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Water-Supply Paper 425

**CONTRIBUTIONS TO THE HYDROLOGY
OF THE UNITED STATES**

1917

NATHAN C. GROVER, Chief Hydraulic Engineer



WASHINGTON

GOVERNMENT PRINTING OFFICE

1919

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CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES, 1917.

NATHAN C. GROVER, Chief Hydraulic Engineer.

GROUND WATER IN SAN SIMON VALLEY, ARIZONA AND NEW MEXICO.

By A. T. SCHWENNESEN.

INTRODUCTION.

LOCATION AND AREA.

San Simon Valley is in southeastern Arizona and the adjacent part of New Mexico. Most of the valley lies in Graham and Cochise counties, Ariz., but a small part of it is in Grant County, N. Mex. (See fig. 1.) The valley extends north-northwestward for 85 miles from the head of San Bernardino Valley, 20 miles north of the Mexican boundary, to the Gila Valley. Its southern part is narrow, averaging about 10 miles in width. It widens toward the north, reaching a maximum width of 35 miles where it is crossed by the Southern Pacific Railroad. North of the railroad it narrows to about 25 miles at a point where it opens into the Gila Valley.

DEVELOPMENT.

The first white settlers came into San Simon Valley in the early seventies. As the climate was arid and dry-farming methods had not been developed, and as there seemed to be no available supply of water for irrigation, they depended for a livelihood upon stock raising. For this purpose the region was particularly well adapted. In the central parts of the valley grass for summer grazing is ordinarily abundant, and the mountains furnish pasturage for the fall and winter, when the grass in the valleys becomes scarce. Large areas of the

valley are covered with brush, mostly creosote, cat's-claw, mesquite, and sagebrush. When the grass crop fails in years of drought stock subsists largely on the sagebrush and the leaves and beans of the mesquite.

Until seven or eight years ago the valley was occupied only by cattle ranches and was consequently very sparsely settled, but since

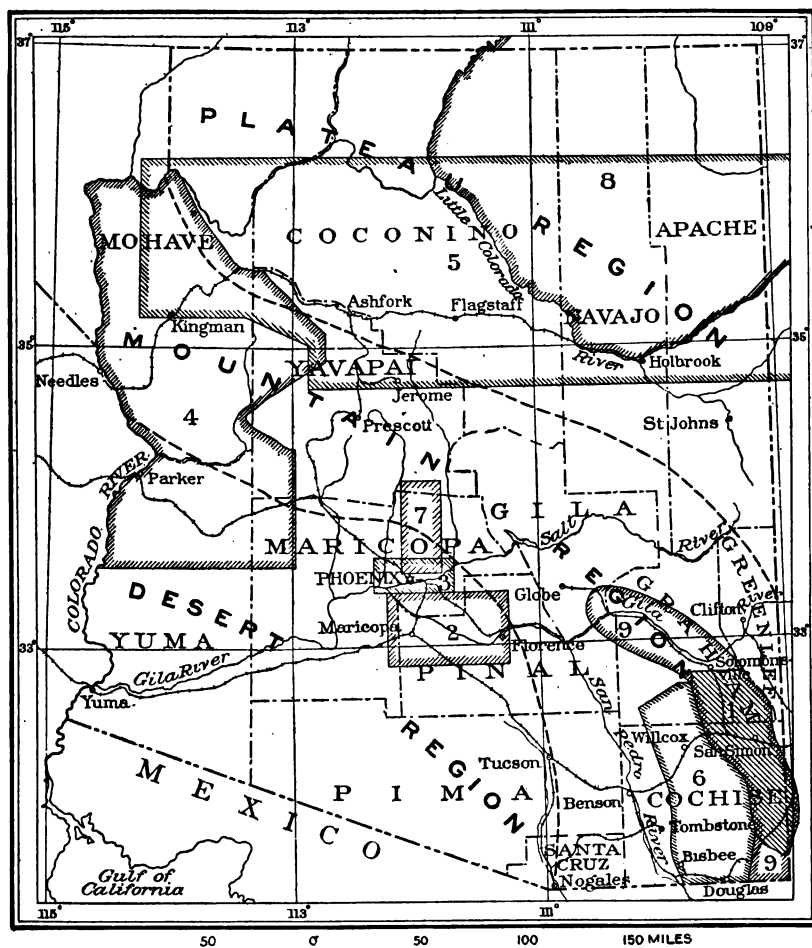


FIGURE 1.—Map showing physiographic provinces in Arizona and areas covered by Survey reports dealing with ground water. 1. San Simon Valley (Water-Supply Paper 425-A, the present paper); 2, Water-Supply Paper 104; 3, Water-Supply Paper 136; 4, Bulletin 352; 5, Bulletin 435; 6, Water-Supply Paper 320; 7, Water-Supply Paper 375; 8, Water-Supply Paper 380; 9, water-supply paper in preparation.

that time there has been a rapid influx of settlers, due chiefly to the discovery of artesian water. This discovery, which was made at San Simon late in 1910, encouraged settlements not only in the vicinity of San Simon but also in other parts of the valley. Before that time

the only known ground-water supply was that from the upper horizon, from which relatively shallow wells were drawing. This supply is adequate for domestic and stock use and also for the heavier demands of the railroads at San Simon and Rodeo, but throughout most of the valley, where the land is suitable for agriculture, the water of this upper horizon is too far below the surface for economical pumping for irrigation. The discovery of a lower formation which contains water under pressure has therefore made irrigation possible over a considerable area, either from flowing wells or from other deep wells in which the water rises near enough to the surface to be profitably pumped.

The principal agricultural areas of San Simon Valley are the San Simon area and Artesia Valley, where artesian water is used for irrigation; the Bowie area, where water for irrigation is pumped from wells; and the Rodeo area, where dry farming, supplemented by irrigation with flood waters, is practiced. The positions of these areas are indicated on Plate I.

SCOPE AND PURPOSE OF REPORT.

The ground-water survey of San Simon Valley was begun in December, 1913, when about 10 days were spent in making discharge and pressure measurements of flowing wells and in collecting samples of water. The field work was completed in the fall of 1915, when the whole valley was investigated in detail and measurements were made wherever possible of the flowing wells that had been measured in 1913 in order to determine how the performance of the wells in 1913 and 1915 compared. Many new flowing wells were also measured and almost all other wells and springs in the valley were visited.

The survey was undertaken by the United States Geological Survey in cooperation with the Arizona Agricultural Experiment Station to obtain reliable information that might be furnished in response to requests received from the general public and that might be used by the Federal Government in the classification of the public lands.

The field work was done and most of the report was prepared by A. T. Schwennesen, of the United States Geological Survey, under the supervision of O. E. Meinzer, who is in charge of the Survey's ground-water investigations. The chapter on agriculture was written by R. H. Forbes, of the Arizona Agricultural Experiment Station. The water analyses were made in the laboratories of the Experiment Station by A. E. Vinson and P. W. Moore. The topographic map was made by Cornelius Schnurr, F. A. Danforth, and S. E. Taylor, of the Geological Survey.

ACKNOWLEDGMENTS.

For well records and other information acknowledgment is especially due the following settlers of the valley: Messrs. J. S. McCrory, Gordon Wharton, G. E. Ebsen, E. A. Washburn, J. D. Averill, J. H. Hibler, J. L. Hill, James Roundtree, A. G. Pierce, Frank Sumrell, and J. B. Garland. Many other settlers also supplied information and extended courtesies. Melvis Smith, driver and general assistant, aided greatly by his intimate knowledge of the region.

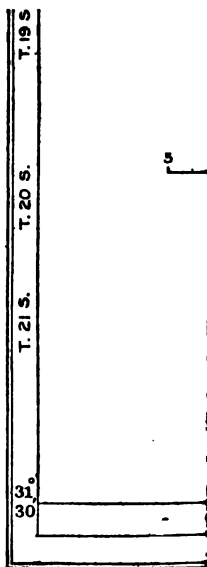
PHYSIOGRAPHY.

BOUNDING RANGES.

San Simon Valley occupies the trough between two nearly parallel mountain chains. On the east the valley is bounded by the Peloncillo Range, which separates it from Animas Valley and the upper Gila Valley. On the west it is separated from Sulphur Springs and Aravaipa valleys by a mountain chain comprising the Chiricahua, Dos Cabezas, and Pinaleno ranges. In the southern part of the region the mountains on both sides of the valley trend almost due north and south, but farther north they swing westward and continue in a northwesterly direction to Gila River.

Along the west side of the valley the mountains are much broader and loftier than on the east side. The Chiricahua Mountains, which form the southern link of this chain, extend from the head of the San Bernardino drainage, about 20 miles north of the Mexican boundary, northward 35 miles to Apache Pass. They are massive and rugged and rise to elevations of more than 8,000 feet above sea level, or 4,000 feet above the valley. Cochise Head has an elevation of 8,100 feet and is one of the most prominent landmarks in the region. The range is timbered, principally with pine, oak, and juniper, and is included in the Chiricahua National Forest. The mountain slopes that rise from San Simon Valley are precipitous and are cut by many canyons, at the mouths of which large, steep alluvial fans extend out into the valley. The principal watercourses are Sulphur, Cave, Turkey, and Whitetail creeks. Most of the streamways carry little or no water during most of the year, even in the mountains, but in times of heavy rain they discharge large amounts into the valley.

The Dos Cabezas Mountains extend northwestward from the Chiricahua Range for 20 miles to the pass through which the Southern Pacific Railroad crosses into Sulphur Spring Valley. The range takes its name from prominent twin peaks, which rise 1,500 to 2,000 feet above the main part of the range to an elevation of about 8,000 feet. The range is almost bare and has no important streamways leading to San Simon Valley.



MAP OF SAN.

The Pinaleno Mountains extend northwestward from the Dos Cabezas Range to Gila River, a distance of about 30 miles, and separate San Simon Valley from Aravaipa Valley. The southern part of the range is low and not very conspicuous, but toward the Gila the crest rises, culminating in Graham Peak. The northern part of the Pinaleno Range is heavily timbered and is included in the Crook National Forest.

The Peloncillo Mountains consist of a single ridge for most of the distance from the south end to Steins Pass, north of which they are much wider and are broken into numerous short, irregular ridges and small mountain groups. Near the north end of the range the Whitlock Hills project into the valley from the main range. The average elevation of the crest of the Peloncillo Range is about 5,500 feet above sea level. The most prominent peaks are Ash Peak (at the northern end of the range), Doubtful Peak, Stein Peak (just north of Steins Pass), and Cienaga Peak (8 miles south of the pass), all of which are approximately 6,000 feet high. The southern part of the range contains some timber and is included in the Chiricahua National Forest, but the greater part of the range is bare. Tule Wells Canyon and Ward Canyon, in the northern part of the range, and Cottonwood, Post Office, Skull, and Skeleton canyons, in the southern part of the range, contain the largest streamways.

On the south San Simon Valley is separated from San Bernardino Valley by a low, inconspicuous divide that extends from a point near the mouth of Texas Canyon, at the foot of the Chiricahua Mountains, eastward to a point at the foot of the Peloncillo Mountains, 3 or 4 miles south of Skeleton Canyon. The El Paso & Southwestern Railroad crosses this divide about $1\frac{1}{2}$ miles south of Moore's Spur.

THE VALLEY.

The valley has the form of a broad, shallow trough, the sides of which are formed by the alluvial slopes that extend down from the bordering mountains. Where the valley is narrow the bases of the alluvial slopes almost meet at the axis, but where the valley is wide it has the appearance of a nearly level plain with upward-curving edges.

At the San Bernardino divide the elevation of the valley is approximately 4,700 feet above sea level, and at the lower-end, where it joins the Gila Valley, it is about 3,000 feet, so that the average grade northward is about 20 feet to the mile. The slopes of the sides are much greater than the axial slope, grades of more than 100 feet to the mile being common.

The drainage of San Simon Valley finds outlet into Gila River through the so-called San Simon Creek. Between the San Bernardino divide and Rodeo the accumulated storm run-off from the

slopes drains through a broad, shallow draw with no very definite outlines. Below Rodeo the draw is one-fourth to three-fourths mile wide and takes more definite shape, its flat bottom being 15 to 20 feet below the general valley surface and bordered by bluffs. The drainage does not follow any definite channel but spreads over the whole of the flat. About 15 miles below Rodeo the draw empties into the San Simon Cienaga, a low, marshy area, in which the ground water is at the surface. This cienaga is 5 miles long, from one-fourth to one-half mile wide, and contains about 1,200 acres. In addition to the drainage from the upper valley, it receives, through Cave Creek, the run-off from some of the highest parts of the Chiricahua Mountains.

San Simon Creek has its source at the lower end of the cienaga and follows the axis of the valley to the Gila. For most of its course it has a deep, narrow channel with high vertical banks. This channel has been formed almost entirely since the region was first settled by Americans. At its source the creek is fed by the nearly perennial overflow from the cienaga, but some distance downstream it is normally dry. In the vicinity of San Simon a small continuous flow is maintained by waste water from the flowing wells. At a number of places in the lower part of the valley the channel has been cut nearly to the ground-water level, and here water may be found, even in the dry season, by making a shallow excavation in the bottom of the channel. For 20 miles back from the Gila the surface is greatly dissected, owing to the lowering of the Gila River valley during late geologic time and the consequent lowering of the outlet for San Simon Creek.

In the upper and middle portions of San Simon Valley the work of the streams is mainly aggradational and consequently the surface of the valley is in general even.

GEOLOGY.

PRE-QUATERNARY ROCKS.

The core of the Pinaleno, Dos Cabezas, and Chiricahua mountains consists of gneisses and schists which were regarded by Gilbert¹ as pre-Cambrian. Unconformably upon this basement lie sedimentary and metamorphic rocks of Paleozoic age, consisting principally of limestone, sandstone, shale, and quartzite. Lavas of probable Tertiary age are also widely distributed.

The Peloncillo Mountains consist principally of igneous rocks and rocks composed of volcanic fragments. These rocks are probably largely of Tertiary age.

¹ Gilbert, G. K., Report on the geology of portions of New Mexico and Arizona examined in 1873: U. S. Geog. and Geol. Surveys W. 100th Mer., vol. 3, pp. 509-513, 1875.

The rocks that outcrop in the mountains no doubt extend beneath the valley and form the floor on which the valley fill was deposited (fig. 2).

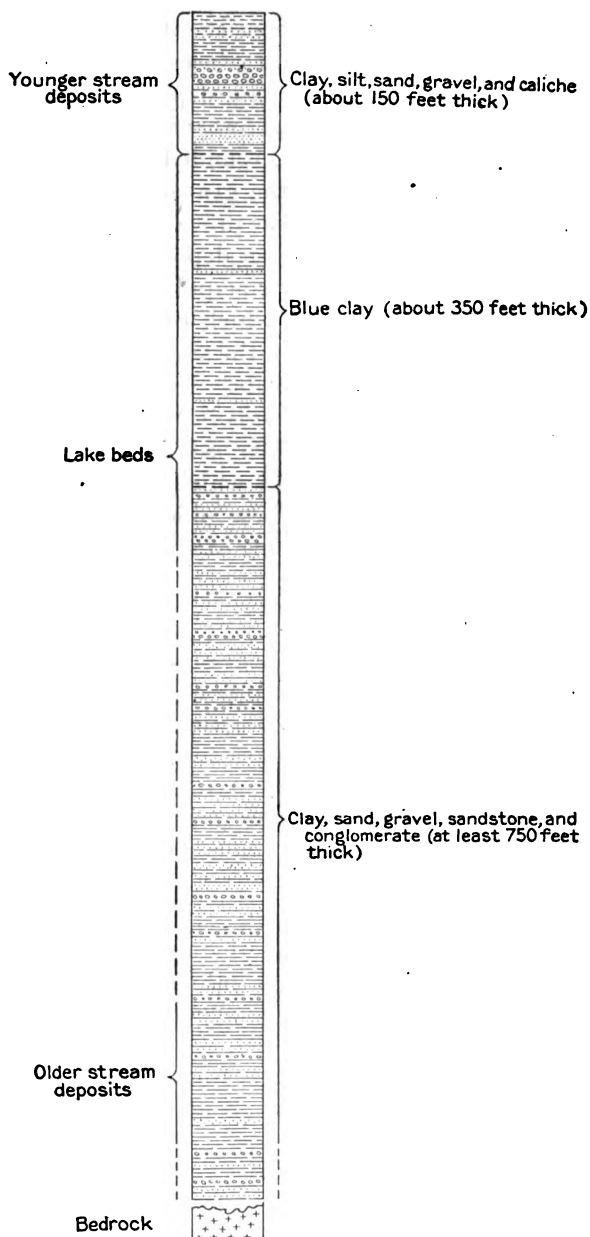


FIGURE 2.—Generalized columnar section of San Simon Valley, Ariz.-N. Mex.

QUATERNARY DEPOSITS.

OLDER STREAM DEPOSITS.

The oldest valley fill apparently consists of stream deposits, which are covered by younger beds in most places and which are difficult to distinguish from the younger stream deposits where they are exposed at the surface. In two places, however, it is believed they have been recognized—in an area of low, rounded gravel hills near Railroad Pass, west of Bowie, and in the gravel hills south of the San Simon Cienaga. The deposits are prevailingly gray, somewhat lighter in color than the recent stream deposits, and contain coarser and better-assorted gravel. The principal distinguishing feature, however, is their hilly topography, which represents a mature stage of erosion and contrasts sharply with the simple aggradational forms assumed by the younger stream deposits. In the general character of their materials and topography the beds in San Simon Valley resemble the gravels which underlie the lake beds in the Gila basin on the San Carlos Indian Reservation and which were identified by the writer as the oldest valley fill. These older stream deposits have probably been reached in at least some of the deeper wells.

LAKE BEDS.

Beds which were deposited in a lake or other body of water outcrop over a large area in the lower dissected portion of San Simon Valley. They consist chiefly of gray, yellow, and greenish-blue clay and gray and reddish sand. The sands are commonly interbedded with thin beds of tuff and thin layers or partings of indurated coarse-grained sandstone. Beds of fine, well-assorted gravel, belonging to the same series, are exposed at a number of places. Structurally they form a very flat syncline whose axis coincides nearly with the axis of the valley.

In the middle and upper portions of San Simon Valley the lake beds are not exposed but are found in wells beneath the surface mantle of stream deposits. Dense, homogeneous, non water-bearing blue clay, 300 to 400 feet thick, which is believed to be the upper member of the lacustrine formation, is found in almost all the wells near San Simon and Bowie within about 150 feet of the surface. This is the confining bed which holds the artesian water under pressure. Beneath the blue clay is a series of beds of gray, yellow, or reddish clays interbedded with sand or fine gravel, as a rule containing thin layers of hard sandstone. In the center of the valley these beds persist to a reported depth of 1,230 feet, which is the greatest depth attained by the drilling. They contain the artesian water

that has been found in this vicinity and are believed to be in part lake deposits but probably include older stream deposits, as the information furnished by the drillers' logs is not sufficiently specific to make it possible to differentiate with certainty between these two kinds of deposits.

In a well drilled to a depth of 1,000 feet at Rodeo, in the upper part of the valley, beds of the same general character and succession as in the vicinity of San Simon were reported. Farther up the valley wells have not been sunk deep enough to reach the lake beds, but their thickness at Rodeo indicates that they extend a long distance south.

YOUNGER STREAM DEPOSITS.

The younger stream deposits lie at the surface over perhaps two-thirds of the area of the valley. They overlies the lake beds, probably mantle the older stream deposits in many places, and lie directly on the pre-Quaternary rocks in some places. At the lower end of the valley they form only a thin covering and have in many areas been eroded away entirely, leaving the underlying lake beds at the surface. Toward the head of the valley they thicken, and in the San Simon and Bowie areas they are usually found in wells to a depth of about 150 feet. Near Rodeo and farther south wells end in the younger stream deposits at depths of 300 to 400 feet.

The younger stream deposits consist of clay, silt, sand, gravel, and boulders, the materials in some of the beds being well sorted and in others mixed. The individual beds are lenticular and as a rule not continuous for great distances.

In the interior portions of the valley the sediments are finer and better stratified than along the edges of the valley, where the rough debris from the mountains has been dumped unsorted.

LAVA BEDS.

Lava covers small areas near the east edge of the valley between Rodeo and Apache and larger areas in the vicinity of Moore's Spur and the San Bernardino divide. The lava is a grayish-black or reddish-brown vesicular basalt. It rests on the valley fill or is interbedded with it.

PRECIPITATION.

SEASONAL DISTRIBUTION AND CAUSE.

The following statements in a report of the United States Weather Bureau,¹ regarding the seasonal distribution and cause of the pre-

¹ Summaries of climatological data by sections: U. S. Weather Bur. Bull. W, vol. 1, sec. 3, pp. 21-22, 1912.

cipitation in southern Arizona and southwestern New Mexico apply in general to the San Simon drainage basin:

The precipitation occurs principally during two portions of the year, a primary maximum fall occurring during the months July to September, inclusive, and a secondary maximum during the colder months of the year. But little precipitation occurs during the later autumn months and practically none at the lower elevations during April, May, and June.

The precipitation of winter is the result of general storm movement over the district, induced by the low areas that develop over the Gulf of California and the lower Colorado Valley, the greater part of the moisture from which, however, is deposited in regions far to the eastward. In the high elevations much of the precipitation of winter occurs as snow.

The rains of summer are local in character and generally traceable to the influence of the mountains interposing their masses to the free passage of the rain-bearing winds. These winds, in their passage over the high elevations, are cooled by the consequent elevation and expansion sufficiently to cause condensation and precipitation, and while the maximum intensity of these local storms of summer is confined largely to the adjacent mountain areas, the upper currents distribute the precipitation to some extent over the adjacent valleys and plains.

RECORDS.

Precipitation records have been kept, with few interruptions, at Bowie since 1867, at San Simon since 1881, at Paradise since 1908, and at Rodeo since 1910. The mean monthly and mean annual precipitation at those places is given in the following table:

Mean monthly and mean annual precipitation, in inches, in the San Simon drainage basin.

Station.	Elevation above sea level (feet).	Length of record (years).	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Bowie.....	3,756	^a 45	0.99	1.57	1.08	0.17	0.27	0.50	2.80	2.79	1.13	0.66	0.72	1.13	13.81
San Simon.....	3,609	^b 33	.43	.52	.64	.10	.13	.15	1.07	1.66	.58	.36	.44	.69	6.77
Paradise.....	5,436	^c 8	.93	1.25	1.15	.33	.11	.85	4.58	3.04	2.01	.82	.93	2.20	18.20
Rodeo.....	4,118	^d 6	.69	.60	.62	.15	.06	.60	2.74	1.59	.98	.92	.46	1.74	11.15

^a No records for years 1895 to 1898, inclusive. Records incomplete for years 1867, 1871, 1872, 1902, and 1913.

^b No records for years 1901 and 1902. Records incomplete for years 1881, 1888, 1889, 1897, 1898, and 1911 to 1914, inclusive.

^c Records incomplete for years 1908, 1911, and 1915.

^d Records incomplete for years 1912 and 1913.

The records show a very irregular distribution of precipitation. The difference in the precipitation at Bowie and at San Simon is striking. Although both places are in the valley only 16 miles apart and the difference in elevation of the two stations is only 153 feet, Bowie receives more than twice as much precipitation as San Simon. The heavier precipitation at Bowie is probably due to the influence of the near-by Dos Cabezas Mountains, which lie directly across the path of the moisture-laden southwest winds. The moisture is con-

densed and mostly precipitated in the mountains, but some of the precipitation is carried into the adjacent valley areas. At Rodeo the precipitation is also much greater than at San Simon. This is due partly to the higher altitude but probably also to the proximity of the lofty Chiricahua Mountains. Paradise, which is a small mining town about 12 miles northwest of Rodeo in the Chiricahua Mountains, receives a much heavier precipitation than any of the stations in the valley.

GROUND-WATER HORIZONS.

In the San Simon and Bowie areas, in the vicinity of Rodeo, and possibly also in the lower part of the valley, there are two separate and distinct ground-water horizons.

The upper horizon is in the mantle of sediments called in this report the younger stream deposits (p. 9). The water in these deposits is under little or no pressure and in wells does not rise appreciably above the water table. It is locally referred to as surface water, and shallow wells that tap only this supply are called surface wells.

The lower ground-water horizon is in the deeply buried sediments beneath the blue clay which lies under the younger stream deposits (p. 8). The water of this lower horizon is under hydrostatic pressure and rises in wells above the level of the upper ground water; in the vicinity of San Simon it rises to the surface.

WATER AT UPPER HORIZON IN SAN SIMON AND BOWIE AREAS.

OCCURRENCE AND SOURCE.

The upper ground water in the San Simon and Bowie areas is found in beds of gravel or sand or in beds that consist of a mixture of these materials. Wells in the vicinity of San Simon usually penetrate one principal water-bearing bed of loose, fairly coarse gravel and several minor water-bearing beds composed of loose, porous sand. The water-bearing beds are separated by beds of red or yellow clay, caliche (carbonate of lime), or impervious mixtures of these materials.

In all the wells in the Bowie area of which records are available the water of the upper horizon was found in sand or in mixed clay and gravel commonly called wash.

The source of the water is the precipitation in the valley and the run-off from the mountainous portions of the drainage basin. The principal intake areas are the steep upper portions of the stream-built slopes. Probably very little of the water that is precipitated or shed on the flatter middle portions of the valley reaches the ground-water level.

DEPTH TO WATER TABLE.

The depth to the water table is less than 100 feet throughout a belt of land that extends along the axis of the valley, including nearly all of the San Simon flowing-well area and also a narrow strip on each side of San Simon Creek north and south of the flowing-well area (Pl. I). The shallowest water is at the San Simon Cienaga, where the water table is practically at the surface. Northward the depth gradually increases until at San Simon the water table is 60 to 70 feet below the surface. Northward from San Simon the water table approaches nearer to the surface in the region bordering San Simon Creek, and at the Triangle Cattle Co.'s well, 4 miles north-northwest of San Simon, it is only 35 feet to water. Below this place the water table apparently slopes northward at about the same grade as the surface of the land, for at the Posey ranch, 15 miles below San Simon, the water table is reported to be about 40 feet below the surface.

Outward from the axis of the valley the depth to water increases. Northeastward up the slopes toward the Peloncillo Mountains and southwestward toward the Chiricahua Mountains the depth to the water table increases rapidly, but on the plain extending westward from San Simon toward Bowie the depth increases more gradually.

YIELD.

In the San Simon area all irrigation supplies are drawn from the lower or artesian horizon, and there are no heavy demands on the supply of the upper horizon except at the pumping plant of the Southern Pacific Co. at San Simon, where two 12-inch bored wells, 133 feet deep, furnish all the water that is required for the railroad's use. For watering stock and for domestic uses the supply has never been known to fail anywhere in the area. In fact, there is every indication that the supply is large and if need be could be drawn upon for irrigation.

In the Bowie area the supply of ground water at the upper horizon is small, and wells, even for stock and domestic uses, must generally be sunk to the lower horizon.

WATER AT LOWER OR ARTESIAN HORIZON IN SAN SIMON AND BOWIE AREAS.

OCCURRENCE AND SOURCE.

The first bed in which the water rises under hydrostatic pressure is generally found immediately under the blue clay, usually at depths of 400 to 600 feet below the surface, below which water-bearing beds

are encountered at intervals to the greatest depth to which wells have been drilled, which in the San Simon area is somewhat more than 1,200 feet. These water-bearing beds are separated by layers of impervious materials, recognized by well drillers as clay, shale, sandstone, conglomerate, cemented gravel, hardpan, concrete, and rock.

The character of the material composing the water-bearing beds differs somewhat in different localities. In the San Simon area the beds on the east side of San Simon Creek, and also those on the west side of the creek in the southern part of the artesian area, generally consist of coarse sand and fine gravel, whereas north and west of San Simon and in the region immediately south of the town the water-bearing beds consist largely of fine sand. In the Bowie area the water-bearing beds in almost all the wells consist of coarse white sand.

In the San Simon and Bowie areas the essential conditions for artesian wells are fulfilled. The beds of sand and gravel serve as the pervious stratum for the entrance and passage of the water, and the blue clay serves as the impervious confining stratum.

Practically all the artesian water of San Simon Valley originates in the rain and snow that fall on the mountainous parts of the San Simon drainage basin and the upper parts of the valley. The supply from this source is large in the aggregate and is by no means inadequate to provide the artesian water that is known to occur in the valley. Some inhabitants of the region believe, however, that ground water from Animas Valley, which lies east of San Simon Valley, seeps into the San Simon basin. It is true that the ground water of Animas Valley lies higher than the level to which the artesian water in San Simon Valley rises, but it is improbable that any great amount of water seeps through the intervening Peloncillo Mountain barrier.

HEAD.

The water that supplies the artesian basin passes into the water-bearing beds in the elevated outcrop zones along the edges of the valley and downward beneath the impervious blue clay. As the water-bearing beds descend from an altitude of about 4,000 to 4,500 feet above sea level at the outcrop zone to an altitude of about 3,000 to 3,500 feet at the center of the basin the water below the blue clay is under considerable pressure. This pressure causes the water to rise in wells when the blue clay is penetrated.

In the flowing-well areas (Pls. I and II) the pressure is sufficient to force the water above the surface. In the Bowie area and in other areas adjacent to the San Simon flowing-well area the pressure is great enough to force the water far above the level of the water-bearing beds but is not sufficient to force it to the ground surface.

In the fall of 1915 the heads in about sixty of the flowing wells in the vicinity of San Simon were measured and were found to range from a fraction of a foot to 42 feet. The average head in all of the wells measured was about 15.5 feet. (See table, pp. 22-26.)

Comparison with measurements made in December, 1913, shows that on the whole there has been a large decrease in head. The average head of eight wells measured in 1913 was 31 feet. In 1915 when the same wells were measured the average head was 19 feet, a decrease of 39 per cent. Five of the wells (Nos. 61, 76, 127, 133 and 148) had lost about 50 per cent of their head, one well (No. 85) had lost 14 per cent, and two wells (Nos. 57 and 104) had gained 71 and 44 per cent, respectively. Whether the loss of head in most of the wells is due to an actual depletion of the artesian supply or to some other cause is not conclusively shown by the data. The fact that some of the wells gained pressure during the interval between 1913 and 1915 suggests that loss of head is not general throughout the area and that in many of the wells it may be due largely to local causes. Faulty well construction is believed to have caused much of the loss of head and the diminishing flow. As a general rule wells are cased for only a short distance into the blue clay and consequently they often become obstructed by the caving of the clay walls and by the sanding up of the uncased bore in the water-bearing beds.

Outside the flowing-well area the hydrostatic pressure is not sufficient to force the water to the surface. Many deep wells have been drilled along the margins of the flowing-well area and in the vicinity of Bowie. The depth to water in these wells ranges from a few feet to over 100 feet. (See table, pp. 22-26.) Throughout a large area on the plain extending west from Bowie and north from Bowie east of the Arizona Eastern Railroad the water in deep wells penetrating to the lower horizon generally rises to levels less than 50 feet below the surface, and that depth is ordinarily considered the limit of economical pumping for irrigation. On the higher ground west and south of Bowie the water does not rise high enough in wells to be economically pumped for extensive irrigation.

YIELD.

The total number of flowing wells listed in the table (pp. 22-26) and shown on the map (Pl. II) is 127. This includes all the wells in the San Simon area that were flowing in October, 1915. The flow of these wells ranges from less than 1 gallon to about 300 gallons per minute, and the average flow from 116 wells measured in 1915 was 52 gallons per minute. The combined yield of the 127 wells, if they flowed continuously, would be approximately 15 second-feet, or 11,000 acre-feet per year. The largest flows are obtained east

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of San Simon Creek, where the average yield is about 80 gallons per minute, and in the southern part of the flowing-well area, west of the creek, where the average flow is about 90 gallons per minute. North, west, and south of San Simon the flows are small, the average being about 12 gallons per minute.

Comparison of the flows of 12 wells measured in 1913 and 1915 shows that in two years the aggregate yield of these wells decreased 45 per cent, and that individual wells showed decreases in flow ranging from 20 to 80 per cent. Whether this is due to the failure of the artesian supply or to other causes is a very important question which affects the welfare of the whole region. No doubt the caving and filling with sand of the uncased portions of the wells has caused much of the decrease in flow, for when failing wells are cleaned out the flow immediately increases, and new wells that are brought in almost invariably yield much more than older wells in the same locality. That the supply is not failing to the extent that the comparisons of the flows in 1913 and 1915 would indicate is shown by the fact that there has been no noticeable shrinking of the flowing-well area and by the fact that the water level in nonflowing deep wells outside of the area has not been lowered to any great extent within the last two years. Many wells along the margin of the area which yielded only very small flows when they were completed are still flowing.

The diminished flow of the wells may in a measure be due to the exceeding dryness of the summer of 1915. This surmise is, however, in itself disquieting, for it would indicate that the storage capacity of the artesian reservoir was small and that the limit of development had about been reached. In that event a large increase in the number of wells and consequently heavier drafts on the supply might cause a serious water shortage in the event of a protracted drought.

None of the flowing wells have been pumped for irrigation sufficiently to prove their capabilities under those conditions and to determine the effect of pumping on the flow of surrounding wells.

In the Bowie area a number of deep nonflowing wells are pumped for irrigation. Yields of 600 to 800 gallons per minute, or 10 to 20 gallons per minute for each foot of drawdown under steady pumping, are reported from some of the larger plants.

METHODS AND COST OF CONSTRUCTING WELLS.

Most of the wells are 4 to 6 inches in diameter and are cased for only 150 to 200 feet—a short distance into the blue clay. Many of the older wells have, however, caved or have been partly filled with sand. At the present time, therefore, the best practice dictates the use of standard casing which is carried to the bottom and perforated at the water-bearing beds.

By the jetting process, which is used almost exclusively, wells can be sunk through the unconsolidated valley fill quickly and cheaply. The charge for putting down wells of the usual size by contract is from 50 to 75 cents per foot. Under the cooperative system, whereby a group of farmers purchase and operate a drilling rig jointly, wells have been put down at even less cost. The average cost of the partly cased flowing wells in the San Simon area is between \$500 and \$600. In the Bowie area the cost of larger wells cased to the bottom and used for pumping is from \$1,000 to \$2,000.

CONSERVATION OF ARTESIAN SUPPLY.

The importance of preventing waste and conserving the artesian supply can not be overemphasized. In the early days of developing many of the wells in the San Simon region were allowed to flow continuously, and the water that was not used ran to waste. Now most of the large wells are fitted with valves so that they can be shut off when not in use, but the flow of a few large wells and many small wells is still wasted. Though the waste from any one well may appear of slight importance, the aggregate annual waste in the district is proportionately very large. When it is considered that a well flowing only 10 gallons a minute discharges over 5,250,000 gallons, or 16 acre-feet, in a year the importance of controlling the flow may be realized. A State law somewhat similar to the one in New Mexico for regulating the construction and use of artesian wells is needed.

QUALITY.

The analyses in the table on page 17 indicate that the waters from the lower horizon in the San Simon and Bowie areas generally contain only moderate amounts of dissolved mineral matter. In 24 of the 25 waters analyzed the total solids range from 224 to 468 parts per million. One water, that from the E. W. Burress well (No. 47) in the western part of the flowing-well area, is very highly mineralized, the analysis showing 6,578 parts per million of total solids. The waters from this part of the area, where the flows are small, are in general more highly mineralized than those from the region of the largest flows east and south of San Simon. As in other valleys of the Southwest in which the valley fill is derived largely from igneous and metamorphic rocks rich in sodium, the waters from the San Simon and Bowie areas of the San Simon Valley are predominantly of the sodium carbonate or "black alkali" type.

*Analyses of ground waters from artesian horizon in San Simon and Bowie areas,
San Simon Valley, Ariz.-N. Mex.*

[Analysts, A. E. Vinson and P. W. Moore, of Arizona Agricultural Experiment Station.]

No. of well. ^a	Constituents in parts per million.						Quality for irrigation.	Quality for domestic use.
	Total solids.	Carbonate radicle (CO ₃).	Bicarbonate radicle (HCO ₃).	Sulphate radicle (SO ₄).	Chloride (Cl).	Permanent hardness as CaSO ₄ .		
22.....	330	21	139	16	6.1	89	Fair.	Good.
25.....	284	0	117	40	18	44	Good.	Do.
28.....	468	48	162	189	9.7	157	Fair.	Fair.
29.....	386	44	48	69	17	85	do.	Good.
30.....	338	28	62	88	13	76	do.	Do.
33.....	312	16	107	80	6.1	123	do.	Do.
47.....	6,578	0	55	4,225	23	1,349	Poor.	Bad.
48.....	418	36	149	86	12	170	Fair.	Good.
61.....	294	0	137	75	7.3	11	Good.	Do.
76.....	286	6.0	119	80	5.4	72	do.	Do.
79.....	322	60	24	72	4.8	98	Fair.	Do.
85.....	330	0	146	80	4.2	8.5	Good.	Do.
104.....	294	22	44	46	4.8	42	do.	Do.
111.....	304	0	122	61	3.6	70	do.	Do.
113.....	282	0	122	74	4.8	64	do.	Do.
121.....	344	0	150	77	8.5	24	do.	Do.
125.....	308	0	149	74	7.3	24	do.	Do.
127.....	284	0	128	65	54	21	do.	Do.
132.....	284	0	124	77	1.2	28	do.	Do.
148.....	302	0	146	72	2.4	17	do.	Do.
149.....	300	0	140	76	6.1	17	do.	Do.
151.....	242	0	146	78	6.6	5.4	do.	Do.
152.....	372	0	168	80	6.6	41	do.	Do.
179.....	224	0	125	37	6.1	25	do.	Do.
182.....	316	0	131	51	6.1	17	do.	Do.

^a Numbers correspond to those used in table of well records (pp. 22-26) and on Pl. II.

All the waters analyzed from the region east and south of San Simon are of good quality for irrigation and domestic use. Although most of these waters are of the sodium carbonate type, the amounts of dissolved salts are so small that with the good drainage outlet afforded through San Simon Creek there is not much danger of the alkali interfering with agriculture. The flowing-well waters analyzed from the region west of San Simon are all classed as "fair" irrigating waters except that from the Burrell well (No. 47), which can not be used for irrigation. The waters classed as fair can be used with safety where the soil is loose and well drained, but on poorly drained soils some precautions would be necessary to prevent accumulation of alkali. For domestic use all the waters are satisfactory except that from well No. 47, which is a poor domestic water because of its high sulphate content and excessive hardness.

In the Bowie area the water from the Blanks well (No. 25) is a good irrigating and domestic water. That from the Bowsher well (No. 22) is fairly good for irrigating and entirely satisfactory for domestic use. As these two waters are believed to be more or less representative, and as the soils are generally sandy and well drained, there should not be much trouble with alkali in this area.

TEMPERATURE.

The usual range in the temperature of the waters is between 77° and 84° F. (See table, pp. 22-26.) In the region east and south of San Simon the temperatures are very uniform, very few of the waters exceeding or falling below these limits. In the region west of San Simon the waters are much warmer, temperatures of more than 90° being common, and at three wells temperatures of more than 100° were observed. These three were the Lyday well (No. 28) and the Baker well (No. 48), where the water has a temperature of 105°, and the Triangle Cattle Co. well (No. 29), where the temperature is 109°. The most plausible explanation for these abnormally high temperatures is that somewhere in their passage underground the waters are heated by uncooled lavas.

GROUND WATER IN THE RODEO AREA.

OCCURRENCE AND SOURCE.

The chief water-bearing formations in the Rodeo area are the younger stream deposits (see p. 9 and fig. 2) that cover almost the entire area. Along the border of the valley these deposits consist largely of coarse gravels which readily absorb the water shed from the mountain slopes. This water percolates downward and fills all the pores in the valley fill below the water table. As the tendency of water is to follow the paths of least resistance and to seek the lowest levels, the largest accumulations of ground water are generally found in the low central parts of the valley.

In that part of the Rodeo area from the vicinity of Apache north to San Simon Cienaga ground-water supplies can be obtained anywhere along the axis of the valley and the adjacent lower portions of the alluvial slopes by sinking wells to the water-bearing gravels and sands. Most wells penetrate at least two water-bearing beds and some three or four. In the central part of the valley northeast of Apache the first water-bearing bed is usually encountered at depths of 100 to 120 feet below the surface, the second between 150 and 170 feet, and the third between 200 and 250 feet. In the vicinity of Rodeo the first water stratum is generally found between 70 and 80 feet, the second between 90 and 100, and the third at about 150 feet. Farther north along the draw leading to San Simon Cienaga the first water-bearing bed usually lies between 50 and 60 feet from the surface, the second at about 70 feet, and the third between 80 and 90 feet. At San Simon Cienaga water is virtually at the surface, and in many wells on the higher ground bordering the cienaga water is found within 25 feet of the surface.

In the Moore's Spur area and the part of the valley between Moore's Spur and Apache ground-water conditions are much less favorable. Most of the supplies in this region are obtained from small springs or seeps, of which there are many in this region. (See Pl. III.) These springs are a result of a reversal of the conditions that govern ground-water supplies in most parts of the valley. Ordinarily the surface waters that percolate into the ground accumulate as ground water in the lower part of the valley fill, where, as a rule, porous beds are found. In this region, however, the lower part of the valley fill is impervious, or at least there is a layer of impervious material near the surface, which prevents the water from sinking and causes it to accumulate in the gravelly upper layers of the valley fill and to break out in springs wherever there is an opening.

DEPTH TO WATER AND QUANTITY.

The position of the water table with respect to the surface is approximately indicated by the water level in wells. The depth to water in all the wells measured during the later part of 1915 is shown on the map of the Rodeo area (Pl. III). The area where the depth to water is less than 100 feet is outlined on the general map (Pl. I).

In the region southwest of Apache and in the vicinity of Moore's Spur the supply of ground water is small. The principal sources of supply are the springs. At a few places spring water is collected in earth reservoirs and used to irrigate gardens and small fields, but generally the springs furnish only enough water for stock and domestic use. As the springs are supplied entirely by the local rainfall the flow differs with the seasons, and during periods of drought most of them diminish greatly in flow or go dry. In some places, principally along the stream courses and in localities where the presence of ground water is indicated by springs, small supplies are obtained from shallow wells. At Moore's Spur some supplies are obtained at depths of 100 to 150 feet from beds of basalt ("malpais") interbedded with the valley fill, but generally attempts to obtain adequate supplies from the deeper valley sediments have been unsuccessful.

In the region from Apache northwest to San Simon Cienaga ground-water conditions are much more favorable. Most of the wells are near the center of the valley, where the supply is largest and also most accessible. As shown by the measurements indicated on the map (Pl. III), the water table slopes with the ground surface but at a lesser rate, so that the depth to water decreases from the edges of the valley down the slopes toward the center of the valley and also northward in the direction of the principal slope of the valley. In the area shown on the map (Pl. I), extending from a line 4 miles

south of Rodeo to San Simon Cienaga and including the central drainage depression and narrow strips on either side, there is approximately 45 square miles where the depth to the water table is less than 100 feet. Outside of this tract the depth to water ranges from 100 to 300 feet, except near the mouths of some of the mountain canyons, where shallow water is found in the gravels overlying the bedrock.

Some idea as to the yield of wells in this region may be gained from the performance of the pumping plant of the El Paso & Southwestern Co. at Rodeo. The plant consists of a 20-horsepower Stover crude-oil engine, a multi-stage Layne centrifugal pump, and a well 13 inches in diameter and 160 feet deep. The normal water level in the well is 80 feet below the surface. The pump is set 100 feet below the surface and discharges into a tank at a point 32 feet above the ground. Under continuous pumping at the rate of approximately 200 gallons per minute the vacuum gage registers 3 pounds per square inch, which is equivalent to a draw down of 7 feet below the pump or a total draw down of 27 feet. The capacity of the well is therefore about $7\frac{1}{2}$ gallons for each foot of draw down. The performance of this plant indicates that while the quantity of water is doubtless sufficient to supply irrigating plants of moderate capacity the lift is so great that pumping for the irrigation of ordinary crops would probably not be profitable.

QUALITY.

As shown by the analyses in the table on page 21, the waters of the Rodeo area generally contain only a moderate amount of dissolved mineral matter. The total solids in the waters analyzed range from 160 to 364 parts per million. Like the waters from the San Simon and Bowie areas they are mostly of the sodium carbonate type, but contain only small amounts of this salt, and, on the whole, they compare favorably with the best deep-well waters in the region to the north. For irrigation and domestic use they are all of good quality.

Analyses of ground waters from Rodero area, San Simon Valley, Arizona-New Mexico.

[Analysts, A. E. Vinson and P. W. Moore, of Arizona Agricultural Experiment Station.]

Source.	Owner and designation.	Location.	Constituents in parts per million.						Quality for irr-igation.	Quality for do-mestic use.
			Total solids.	Carbon-ate radicle (CO ₃).	Bicar-bonate radicle (HCO ₃).	Sulphate radicle (SO ₄).	Chloride (Cl).	Permanent hardness as CaSO ₄ .	Black alkali as Na ₂ CO ₃ .	
Spring...	Price Canyon School...	Sec. 28, T. 20 S., R. 30 E., Ariz.	224	0	38	36	14	Neutral...	Neutral...	Good...
Do.....	Moody Spring.....	SE. 1/4 sec. 36, T. 20 S., R. 30 E., Ariz.	176	0	40	24	6.5	11	13	Do.....
Do.....	School seeps.....	NE. 1/4 sec. 33, T. 20 S., R. 31 E., Ariz.	192	0	62	23	4.5	.....	11	Do.....
Do.....	Squaw Springs (N. A. Neeley).....	NW. 1/4 sec. 14, T. 20 S., R. 31 E., Ariz.	192	0	49	44	6.7	.....	Neutral...	Do.....
Well.....	Mrs. M. K. Morgan.....	NW. 1/4 sec. 6, T. 20 S., R. 32 E., Ariz.	180	0	55	21	8.0	.....	3.2	Do.....
Spring.....	Mr. Darter.....	SW. 1/4 sec. 22, T. 19 S., R. 32 E., Ariz.	358	0	55	71	14	.....	2.1	Do.....
Well.....	San Simon Cattle Co. (Harcott's well).....	NE. 1/4 sec. 10, T. 19 S., R. 32 E., Ariz.	190	0	76	17	12	.....	.....	Do.....
Do.....	Paul McCarty.....	SW. 1/4 sec. 25, T. 28 S., R. 23 W., N. Mex.	180	0	79	14	12	.....	13	Do.....
Do.....	D. M. Phillips.....	NW. 1/4 sec. 1, T. 26 S., R. 22 W., N. Mex.	132	0	86	20	13	.....	11	Do.....
Do.....	El Paso & Southwestern Co.	Rodero, N. Mex.	218	0	19	11	12	.....	15	Do.....
Do.....	C. E. New.....	do.....	248	0	39	8.2	11	.....	19	Do.....
Do.....	Mr. Gilbert.....	SW. 1/4 sec. 36, T. 26 S., R. 22 W., N. Mex.	304	0	229	22	6.1	98	.....	Do.....
Do.....	Mr. Edwards.....	NE. 1/4 sec. 31, T. 27 S., R. 21 W., N. Mex.	334	0	171	32	10	.....	.....	Do.....
Do.....	San Simon Cattle Co. (head-quarters).....	SW. 1/4 sec. 33, T. 18 S., R. 32 E., Ariz.	180	0	70	9.5	12	.....	11	Do.....

DEEP WELLS IN SAN SIMON VALLEY.

The following table presents the data collected in 1913 and 1915 regarding wells in the San Simon and Bowie areas that end in the lower or artesian horizon.

Records of wells in San Simon and Bowie areas ending in lower or artesian horizon.

T. 12 S., R. 28 E.

No.	Location in town-ship.		Owner or designation.	Elevation of mouth of well above sea level.	Depth.	Diameter of casing at top.	Measurements.			
	Section.	Quarter.					Date.	Height of water above (+) or below (-) sur- face.	Flow per min- ute.	Temperature of water.
1	13	NW.	G. C. Davis.....	<i>Feet.</i> 3,612	<i>Feet.</i> 770	<i>In.</i> 6½	Dec. 15, 1915	<i>Feet.</i> — 72	<i>Galls.</i>	<i>° F.</i>
2	17	SE.	J. O. Gurley.....	3,730	567	6½	Dec. 16, 1915	a— 70	.....	.....
3	19	SE.	E. Craig.....	.....	485	8	do.	— 145	.....	.....
4	21	SE.	D. Grimshawe.....	.....	a 500	4	Dec. 15, 1915	— 40	.....	.....
5	25	SW.	Westley Wheeler.....	3,660	500	5	do.	— 29	.....	.....
6	27	.....	J. A. Wheeler.....	.....	333	4	do.	a— 60	.....	.....
7	28	SE.	do.	.....	328	4	do.	a— 60	.....	.....
8	29	NE.	Geo. B. Rentchler.....	.....	200	5½	do.	a— 110	.....	.....
9	34	SW.	W. V. Griffith.....	.....	.....	4	do.	a— 70	.....	.....
10	35	SW.	J. W. Lancaster.....	.....	334	4	do.	— 41	.....	.....

T. 12 S., R. 29 E.

11	8	SE.	Mr. McFarland.....	.....	548	4	Dec. 15, 1915	a— 30	.....	.....
12	33	SW.	Henry D. Sweet.....	.....	1,088	8½	Dec. 13, 1915	— 92	.....	.....
13	33	SW.	do.	.....	780	8½	do.	.....	.....	.....
14	35	SW.	Mr. Goode.....	.....	a 900	12	do.	— 18	.....	.....

T. 13 S., R. 28 E.

15	4	SE.	Bowie Improvement Co.....	.....	435	8	Dec. 16, 1915	— 106	.....	.....
16	13	NE.	W. G. McCampbell.....	.....	440	5½	Dec. 12, 1915	— 49	.....	.....
17	13	NE.	do.	.....	610	8½	do.	— 50	.....	.....
18	13	NW.	H. Kluge.....	.....	595	5½	do.	— 50	.....	.....
19	22	NE.	H. L. Deffenbaugh.....	.....	300	4	Dec. 14, 1915	— 80	.....	.....
20	24	SW.	T. M. Winsor.....	.....	530	5½	Dec. 12, 1915	— 100	.....	.....

T. 13 S., R. 29 E.

21	6	SW.	L. C. Breniser.....	.....	835	6½	Dec. 13, 1915	a— 5	.....	.....
22b	7	SE.	M. C. Bowsher.....	.....	482	4	do.	.....	.....	.....
23	7	SW.	G. Killough.....	.....	656	5½	Dec. 11, 1915	— 23	.....	.....
24	17	NW.	Alice C. Burnett.....	3,700	597	6½	do.	— 20	.....	.....
25b	18	NW.	J. G. Blanks.....	.....	880	8½	do.	— 40	.....	83
26	19	NW.	H. E. Galloway.....	.....	463	9	do.	— 45	.....	.....
27	.....	.....	W. D. Armstrong.....	3,651	601	4	do.	— 30	.....	.....
28b	24	SE.	Mrs. E. M. Lyday.....	.....	960	6½	do.	.....	26	105

a Approximate.

b For analysis of water, see p. 17.

Records of wells in San Simon and Bowie areas ending in lower or artesian horizon—Continued.

T. 13 S., R. 30 E.

No.	Location in town-ship.		Owner or designation.	Elevation of mouth of well above sea level.	Depth.	Diameter of casing at top.	Measurements.			
	Section.	Quarter.					Date.	Height of water above (+) or below (-) sur- face.	Flow per min- ute.	Temperature of water.
				Feet.	Feet.	In.		Feet.	Galls.	° F.
29 ^a	3	NW.	Triangle Cattle Co.....	3,553	860	4	Dec. 29, 1913	.....	^a 10	109
30 ^b	9	NE.	Fred H. Jones.....	3,569	900	5	Oct. 28, 1915	+13	5	109
31	11	NW.	J. B. Moore.....	3,566	950	6	Dec. 29, 1913	.....	.....	98
32	13	NE.	Miss L. K. Stanbery.....	3,567	760	3	Oct. 26, 1915	+18	8	93
33 ^b	14	SE.	Globe Co.....	3,588	.....	9 ¹ / ₂	Oct. 25, 1915	+11	11	88
34	15	SE.	Mary C. Miller.....	3,580	.....	9 ¹ / ₂	Dec. 29, 1913	.....	30	90
35 ^c	18	SW.	J. F. Dowdle.....	3,608	900	5	Oct. 25, 1915	.....	21	90
36	23	NW.	M. Q. Hardin.....	3,563	900	6	Dec. 29, 1913	.....	23	96
37	23	SW.	Geo. H. Ebsen.....	3,565	.....	5	Oct. 26, 1915	.....	18	96
38	24	NE.	W. C. Morrison.....	3,593	860	4	Dec. —, 1913	(^d)	9	67
39	25	NE.	Mrs. Lewis.....	3,607	880	5	Oct. 26, 1915	+9	9	92
40	25	NE.	do.....	3,607	880	5	do.....	.....	.....	.....
41	25	NE.	Geo. E. Sligh.....	3,610	900	5	Oct. 27, 1915	+3	9	84
42	25	NE.	do.....	3,608	.....	4	do.....	.....	1	77
43	25	SE.	Mrs. Stencil.....	3,607	.....	5	do.....	+19	45	81
44	26	NE.	Thos. Lane.....	3,597	.....	6 ¹ / ₂	Oct. 26, 1915	-11	.....	.....
45	26	NW.	J. H. Averill.....	3,594	935	2	do.....	.....	1	84
46	26	NW.	do.....	3,594	860	4	do.....	+9	1	78
47 ^b	26	NE.	E. W. Burress.....	3,603	1,230	5	Dec. 10, 1915	.....	(^e)	.....
48 ^b	30	NW.	B. F. Baker.....	3,661	930	5	Dec. 29, 1913	.....	^a 10	105
49 ^c	30	SW.	G. N. Pettie.....	3,696	810	11 ¹ / ₂	Dec. 11, 1915	.....	2	105
50	35	NE.	Morgan Wilson.....	3,610	1,000	4 ¹ / ₂	Oct. 23, 1915	.....	(^d)	69

T. 13 S., R. 31 E.

51	8	SW.	Walter C. Wiley.....	.....	400	4	Oct. 19, 1915	-33	.....	.....
52	17	NE.	Mr. Herald.....	3,640	.....	.....	do.....	-30	.....	.....
53	17	NW.	Triangle Cattle Co.....	.....	560	5	do.....	.....	1	.....
54	17	.....	A. E. Palmer.....	.....	.....	4	do.....	+5	30	84
55	17	SW.	do.....	.....	840	5	Oct. 18, 1915	+13	2	79
56	18	NE.	Sam L. Gray.....	.....	610	4	do.....	+8	3	83
57	18	SW.	R. B. Cornett.....	3,566	.....	4	Dec. 29, 1913	+14	10	83
58	19	NE.	Chas. Welch.....	3,604	550	5	Oct. 25, 1915	+24	6	83
59	19	SW.	G. B. Barnett.....	3,592	840	4	Oct. 18, 1915	.....	(^d)	.....
60	20	NW.	A. E. Palmer.....	3,609	560	5	Dec. 30, 1913	.....	12	82
61 ^b	20	NE.	Wm. Gregg.....	3,618	.....	4	Oct. 25, 1915	+26	8	82
62	20	NE.	Geo. B. Marshall.....	.....	590	4	Oct. 19, 1915	+12	24	84
63	20	SW.	John Vest.....	3,609	660	4	Oct. 19, 1915	+11	45	84
64	20	SE.	James Salyer.....	3,616	640	5	Oct. 19, 1915	+10	64	83
65	20	SE.	Mrs. Gordon Wharton.....	3,623	615	4	Oct. 18, 1915	.....	1	73
66	20	SE.	Walter Grant.....	3,626	.....	5	do.....	+18	24	84
67	21	SE.	Mr. Hedrick.....	.....	550	4	Oct. 19, 1915	+18	111	83
68	21	SE.	do.....	.....	600	4	do.....	+27	136	83
69	22	SW.	A. B. Hulsey.....	.....	508	4	Oct. 20, 1915	+9	58	80
70	22	SW.	do.....	.....	.....	4	do.....	-13	9	12
71	22	SW.	Mr. Jennings.....	.....	.....	5	do.....	-11	.....	.....
72	27	SW.	do.....	.....	610	4	Oct. 20, 1915	.....	.....	.....
73	28	NW.	R. O. Merritt.....	3,637	673	4	do.....	-26	.....	.....
74	28	NE.	J. C. Campbell.....	3,661	549	6 ¹ / ₂	do.....	+26	164	82
75	28	.....	Walter Grant.....	3,638	625	5	Dec. 30, 1913	.....	.....	.....
76 ^b	29	NE.	G. E. Darsey.....	3,618	618	4	Oct. 20, 1915	+12	51	82
							do.....	+30	107	81
							Dec. 30, 1913	+51	54	78
							Oct. 20, 1915	+26	13	79

^a Estimated.^b For analysis of water see p. 17.^c Casing pulled and well filled up.^d Less than 1.^e Very small.

Records of wells in San Simon and Bowie areas ending in lower or artesian horizon—Continued.

T. 13 S., R. 31 E.—Continued.

No.	Location in town-ship.		Owner or designation.	Elevation of mouth of well above sea level.	Depth.	Diameter of casing at top.	Measurements.			
	Section.	Quarter.					Date.	Height of water above (+) or below (-) sur- face.	Flow per min- ute.	Temperature of water.
77	29	SE.	G. E. Darsey.....	Feet.	760	4	Oct. 20, 1915..	+42	95	81
78	30	SW.	C. E. Smith.....						1	
79 ^a	30	SW.	San Simon Townsite Co.		850	6				
80	30	SE.	James Hancock.....		1,008	5	Oct. 22, 1915		5	79
81	31	NW.	Mrs. Winslow.....		1,200	8 ^b	do.			
82	31	NW.	do.			5	do.		19	83
83	31	SW.	John Homrichausen.....		884	5	Oct. 23, 1915		36	84
84	31	SE.	Guy Pannel and Gordon Wharton.	3,624	850	5	Oct. 22, 1915		36	82
85 ^c	33	NE.	F. J. Barnes.....	3,652	590	5	Dec. 30, 1913	+29	^b 200	80
86	33	SE.	M. T. Bruce.....		690	3	Oct. 20, 1915	+25	144	
87	33		do.	3,645	663	5	do.		21	81
88	33	SE.	A. M. Bruce.....			5	do.	+31	170	81
89	33	SE.	J. M. Hall.....		660	5 ^b	do.	+23	120	
90	34	NW.	W. F. Frye.....		830	5 ^b	Oct. 4, 1915	+20	91	
91	34	SW.	Mr. Hall.....	3,670	c 600	4	do.	+4	36	
							do.	+11	23	

T. 14 S., R. 30 E.

92	1	SW.	A. L. Paschall.....	3,644	920	5	Oct. 23, 1915		2	81
93	2	SW.	H. O. Carr.....	3,661	987	8 ^b	Sept. 29, 1915		(^d)	
94	12	NE.	Frank Meade.....	3,649	1,040	5	Oct. 21, 1915			
95	12	NE.	do.	3,649		9 ^b	do.		^e 45	82
96	12	NE.	do.	3,649	880	7 ^b	do.		1	78
97	13	SE.	Mr. Russell.....	3,699	743	4	Oct. 15, 1915	+9	(^d)	72

T. 14 S., R. 31 E.

98	3	NE.	W. S. Smith.....	3,695	500		Oct. 4, 1915	-3		
99	3	NE.	do.	3,695	756	5 ^b	do.	-3		
100	3	NW.	E. C. Adams.....	3,658	626	5	do.	+24	95	80
101	3	SW.	F. J. Barnes.....		704	5	Oct. 17, 1915	+24	166	75
102	3	SE.	A. G. Pierce.....		650	6 ^b	Oct. 4, 1915		4	
103	3	SE.	do.		580	6 ^b	do.	+2	3	
104 ^c	4	NE.	Stella E. Ebsen.....	3,639		5	Dec. 26, 1913	+9	17	
105	4	SW.	John W. Toles.....		570	5	Oct. 17, 1915	+13	23	74
106	5	NW.	Mrs. Collier.....	3,628		5	do.	+15	45	76
107	5	SW.	Luther Thorstenberg.....	3,631	770	4	do.		(^f)	
108	6	NW.	J. H. Hibler.....		640	5 ^b	do.		19	78
109	6	NW.	Olan Hanum.....		900	4	Oct. 22, 1915		(^d)	
110	7	SW.	Chas. Tompkins.....		760	4	Oct. 16, 1915		45	77
111 ^a	7	SE.	H. S. Chamberlain.....	3,659		4	Dec. 27, 1913	+30		
112	7	SE.	do.	3,659		4	Oct. 16, 1915	+33	36	77
113 ^a	8	NE.	Lee Adams.....		796	5	do.		8	78
114	8	NE.	do.		820	5	do.			
115	8	NE.	do.		800	5	do.			
116	9	SW.	M. H. Butler.....		800	5	Oct. 15, 1915		46	80
117	9	SE.	San Simon Land & Water Co.	3,633	775	5 ^b	Oct. 17, 1915		107	78
118	10	NE.	J. E. Somervell.....	3,674	663	5 ^b	do.	+23	222	80
119	10	NW.	E. A. Washburn.....	3,655	624	6	Oct. 13, 1915	+7	24	74
120	10	SE.	M. R. La Rue.....		650	6	Oct. 6, 1915		29	
121 ^a	10	SE.	do.		650	6 ^b	Oct. 6, 1915		269	78
122	11	SW.	J. A. Shaw.....	3,681	433	4	Oct. 6, 1915		25	76
123	11	SW.	do.		730	5 ^b	do.	+2	1	72
124	13	NW.	R. B. Cornett.....		520	4	do.	-7		
125 ^a	13	SW.	Eugene Belch.....	3,705	490	4	do.	+13		80
126	13	SW.	do.	3,705	530	4	do.		3	76
127 ^a	14	NW.	M. T. Bruce.....	3,678	440	4	Dec. 28, 1913	+45	122	
128	15	NW.	E. A. Washburn.....		822	9 ^b	Oct. 5, 1915	+20	60	75
129	15	NW.	do.		790	9 ^b	Oct. 14, 1915		206	79
							do.	+36	274	80

^a For analysis of water see p. 17.
^b Estimated.
^c Approximate.

^d Less than 1.
^e Combined flow.
^f Small.

Records of wells in San Simon and Bowie areas ending in lower or artesian horizon—Continued.

T. 14 S., R. 31 E.—Continued.

No.	Location in township.		Owner or designation.	Elevation of mouth of well above sea level.	Depth.	Diameter of casing at top.	Measurements.				
	Section.	Quarter.					Date.	Height of water above (+) or below (-) surface.	Flow per minute.	Temperature of water.	
130	15	SW.	E. A. Washburn	Feet. 3,676	Feet. 726	In. 5½	Oct. 14, 1915	Feet. 74	Galls. 79	° F. 79	
131	15	SW.	do.	3,676	726	4	do.	125	83	83	
132 ^a	16	SE.	do.	3,674	715	4	do.	31	79	79	
133	17	NE.	Dr. J. P. Rice	3,657	830	4	{Dec. 28, 1913 Oct. 15, 1915	+38 +16	55 18	84 84	
124	17	NW.	do.			5	do.	+27		79	
135	19	NW.	Wm. Homrichausen		1,140	5½	do.		1	70	
136	20	NE.	G. J. Purdy			4	do.	+7	3	83	
137	20		S. B. Morrow				do.				
138	20	SE.?	F. W. Bartlett			4	do.	+8	5	86	
139	20	SW.	Mr. Foxworth	3,727	1,052	10	Oct. 9, 1915		1	77	
140	21	NE.	Will Buck		875	5	Oct. 15, 1915	+16		84	
141	21	NE.	do.	3,696	730	4½	do.				
142	21	SW.	Dr. W. N. Stewart		770	4	do.	+7	4	85	
143	21	SE.	C. R. Anderson	3,706	800	4	Oct. 9, 1915	+11	34	88	
144	22	NE.	J. D. Averill		620	5	Oct. 7, 1915	+10	28	75	
145	22	NW.	Mr. Cox	3,694			Oct. 13, 1915	+8	9	80	
146	22	SW.	C. E. Wharton	3,704	750	4	Oct. 9, 1915	+9	40	85	
147	22	SW.	do.	3,701	760	4	do.		b 30		
148 ^a	22	SE.	Mrs. S. M. McKinney	3,702	770	4	{Dec. 27, 1913 Oct. 13, 1915	+38 +17		83	
149 ^a	23	NW.	Peter Jensen	3,692	705	5	{Dec. 24, 1913 Oct. 7, 1915		432 250		
150	23	NW.	do.		725	5½	do.		250	84	
151 ^a	23	SW.	do.	3,711	750	5	do.	+11		83	
152 ^a	23	SE.	Mrs. Lizzie Hammons		620	5	Oct. 16, 1915	+10	180	80	
153	23	SE.	do.	3,709	720	5½	Oct. 7, 1915	+9		86	
154	23	SE.	do.		580	5½	do.	+9	90	79	
155	24	NW.	Mrs. Hegie	3,698	590	5	Oct. 6, 1915	+18	87	77	
156	25	NE.	Mrs. Frank Lewis	3,714	640	5½	Oct. 7, 1915	+17	134	80	
157	25	NW.	Albert Jones	3,713		4	do.	+12	65	86	
158	25	NW.	do.			5½	do.	+9	60	78	
159	25	SE.	J. L. Hill		660	6½	do.	+13	137	83	
160	26	NE.	H. O. Carr		800		Oct. 9, 1915				
161	26	NW.	do.		735	5	do.		22	81	
162	26	NW.	do.	3,720	920	4	do.		b 25	84	
163	26	NW.	do.	3,724	800	5½	do.		b 20		
164	26	SW.	Mr. Payne	3,742		5	Oct. 16, 1915	-5			
165	27	NW.	A. S. McKinney		740	4	Oct. 9, 1915		3	83	
166	27	SW.	J. J. Rhodes		885	5½	Oct. 16, 1915	-14			
167	28	NE.	A. Cummins		780	5	{Dec. 27, 1913 Oct. 8, 1915	+17 -5	70		
168	33	SE.	Verne A. Garrison		791		Oct. 2, 1915	c -3			
169	34	NW.	Jeff D. Reagan		791		do.	d -30			
170	35	NE.	J. S. McCrory	3,758	800	4	Oct. 16, 1915	-18			
171	35	SE.	Wm. Maude		707	6½	do.	-35			

T. 14 S., R. 32 E.

172	18	NE.	E. E. Voglar		520	4	Oct. 5, 1915	e -36		
173	19	NW.	Arthur Starr	3,710	390	5½	Oct. 6, 1915		b 20	75
174	19	SW.	Dr. I. R. Kight	3,711	441	5½	Oct. 7, 1915		f 300	80
175	19	SW.	do.	3,704	207	5½	Oct. 6, 1915		254	73
176			F. J. Graham		350	4	Oct. 5, 1915	-6		
177	29	NW.	A. Olander		360	5½	do.	-7		
178	29	NW.	F. J. Graham		410	5½	Oct. 6, 1915	-23		
179 ^a	29	SW.	A. Olander	3,725	350	4	Dec. 23, 1913		34	70
180	29	SE.	W. A. Paul		760	7½	Oct. 5, 1915	+5	17	
181	29	SE.	John Reeden		300		Oct. 6, 1915	-18		
182 ^a	30	NW.	J. L. Hill		560	4	Oct. 7, 1915			
183	31	NW.	Mr. Minges	3,738	d 430	5	Oct. 16, 1915		20	78
184	32	NE.	Dr. J. R. Kight	3,744	409	5½	Oct. 6, 1915	-5		

e For analysis of water, see p. 17.

b Estimated.

c When first drilled.

d Approximate.

e When first drilled; well now filled up.

Records of wells in San Simon and Bowie areas ending in lower or artesian horizon—Continued.

T. 15 S., R. 32 E.

No.	Location in town-ship.		Owner or designation.	Elevation of mouth of well above sea level.	Depth.	Diameter of casing at top.	Measurements.			
	Section.	Quarter.					Date.	Height of water above (+) or below (-) surface.	Flow per minute.	Temperature of water.
				<i>Fect.</i>	<i>Fect.</i>	<i>In.</i>		<i>Fect.</i>	<i>Galls.</i>	<i>° F.</i>
185	4	.....	H. F. Copeland		a 400	5	Oct. 29, 1915	-19	.....	.....
186	5	NW.	John Kirby		520	4	Oct. 7, 1915	-3	.....	.....
187	5	NW.	do.		390	3	do. ....	.....	.....	.....
188	5	NW.	do.		603	4	do.	-12	.....	76
189	6	SE.	C. N. McLarty		572	4	do.	-32	.....	.....

a Approximate.

b When first drilled; well now filled up.

FLOWING WELLS IN ARTESIA VALLEY.

Artesia Valley occupies an erosional trough in the Quaternary Lake beds in the lower part of the San Simon basin, at the eastern base of the Pinaleno Mountains. The valley is one-half to 2½ miles wide, trends northeast, and drains into the Gila Valley. The bottom of the valley is flat and from 25 to 100 feet below the general surface of the basin. In the vicinity of Artesia, where the valley is widest, there are several thousand acres of good farming land, a part of which is irrigated by water from flowing wells.

The artesian conditions in Artesia Valley are similar to those in the San Simon flowing-well area. The water is found in sand or "honeycomb" sandstone overlain by impervious clay, generally blue, but in some places red or white. The first flows are generally encountered between 200 and 400 feet from the surface and succeeding flows at different levels to depths of about 900 feet.

The wells range in depth from 400 to 900 feet and are generally 3 to 6 inches in diameter. Most of the wells are cased only in part, and some of them have only one joint of casing at the top. In many of the old wells wooden casing was used.

Between 30 and 40 wells were flowing in 1915. The flows ranged from only a few gallons to 150 gallons per minute. Many of the older wells that are cased only at the top have caved or filled with sand, so that the flow has diminished greatly or ceased entirely. Some of the larger and better constructed wells have been flowing at an undiminished rate for several years.

Few of the wells are fitted with valves, and consequently there is a large waste of water, especially during the times when the demands for irrigation are light. As the water contains considerable dissolved mineral matter the raising of the water level has caused heavy accumulations of alkali in the soil in the lower part of the settlement.

IRRIGATION.

FLOWING WELLS.

In the San Simon flowing-well area about 1,500 acres were irrigated by flowing wells in 1915. (See Pl. II.) Most of the irrigated lands are in the eastern and southern part of the flowing-well area, where the flows are large enough for irrigation on a commercial scale. North and west of San Simon the yield of the wells is generally too small except for the irrigation of gardens.

From some of the larger wells the water is run directly into the ditches, but the usual practice is to store it in earth reservoirs, from which it is run onto the land. In this way considerable water is lost by seepage and evaporation, but the entire flow of the wells is more completely utilized and a more effective irrigating stream is obtained.

In Artesia Valley about 800 acres is irrigated from flowing wells.

PUMPING.

In the San Simon area several pumping plants are in operation and others are being installed. The total acreage irrigated by pumping in 1915 was about 150 acres. The plants are located over deep wells outside of the flowing-well area, where the water does not reach the surface, and over flowing wells whose yield is insufficient for irrigation.

In the part of the Bowie area lying east and north of Bowie the water in deep wells rises near enough to the surface to be profitably pumped for irrigation. In 1915 a number of plants were in operation and about 300 acres was irrigated.

SUMMARY OF CONCLUSIONS.

1. Practically all the water in San Simon Valley is derived from the precipitation on the drainage basin; there is no considerable inflow of water from other basins.

2. In the San Simon and Bowie areas there are two distinct ground-water horizons; an upper horizon in the younger stream deposits and a lower or artesian horizon in the deposits below the dense clay of the lake beds.

3. In the San Simon area the ground water of the upper horizon is less than 100 feet below the surface throughout a large tract

extending along the axis of the valley. The supply has proved ample for watering stock, for domestic needs, and for the heavier demands of the railroad, and if it can be pumped economically it is probably large enough for considerable irrigation. It is doubtful, however, whether it would be profitable at present to pump this supply for irrigation. In the Bowie region the supply at the upper ground-water horizon is very scanty and it is generally necessary to sink to the lower horizon, even for small supplies.

4. In the lower ground-water horizon the water is under hydrostatic pressure, so that it rises in wells when the water-bearing beds are penetrated. In the San Simon flowing-well area the pressure is sufficient to cause this water to rise above the surface in wells. In the Bowie area the water is also under pressure and in some localities it rises close enough to the surface to be economically pumped for irrigation.

5. Measurements show that the head and yield of wells has decreased considerably in the two-year period between 1913 and 1915. This decrease is largely due to the filling of the uncased wells with sand and the caving of the walls of these wells, but it may in part be due to the increase in the number of wells and depletion of the artesian supply.

6. It is of the utmost importance for the future welfare of the valley that all wells be properly cased to the bottom with heavy casing and be fitted with valves which will be closed when the water is not needed. Faulty construction of wells and waste of artesian water will result in disaster, just as they have in other artesian basins.

7. The flowing-well waters are mostly of the sodium carbonate type, but they generally contain only small amounts of dissolved solids and are of good quality for irrigation and domestic use.

8. In the vicinity of Apache and Moore's Spur the ground-water supply is small and uncertain, but some water for stock and domestic purposes is obtained from shallow wells and springs. In the vicinity of Rodeo and in the central part of the valley north of Rodeo there is a considerable area in which the depth to the water table is less than 100 feet. In this area the supply is probably large, but on account of the lift that would be required it would probably not be profitable at present to pump it for irrigation.

9. All the waters analyzed from the Rodeo area are good irrigating and domestic waters.

AGRICULTURE.

By R. H. FORBES.

HISTORICAL NOTES.

San Simon Valley, like most other valleys of central and southern Arizona, contains traces of a crude prehistoric agriculture. Near the confluence of San Simon Creek with Gila River, above the village of San Jose, are the remains of an ancient ditch, several miles long, which served a large Indian town that was situated just east of Solomonsville. In the ruins of this town numerous artifacts of stone and pottery have been found. In the artesian district on the east slope of Graham Mountain small rectangles formed of man-handled stones mark the foundations of the primitive dwellings of an unknown race; and burial urns containing charred human remains and awls and needles of antelope and turkey bone have been dug up in this vicinity.

On the mesas north of the Gila, opposite its junction with San Simon Creek, there are considerable areas of level land, the stones from which have been collected in irregular rows to form numerous small plots of cleared ground. These may have been camp grounds, or possibly, during the summer rainy season, they may have been used for the culture of aboriginal crops, such as corn and beans. Corn, beans, and native cotton have been found in cliff dwellings on Bonita Creek, a few miles distant. All this is evidence that the region was formerly inhabited by more or less sedentary peoples, who must have supported themselves partly by hunting and partly by a primitive agriculture.

Civilized occupation of the region did not begin until the sixties of the last century, when a colony of Mexicans settled the village of San Jose, near the mouth of San Simon Creek, and irrigated their land with water from the Gila. They were followed by Americans, at Solomonsville, in 1870, and by subsequent colonies at Safford and in the Artesia district.

American cattlemen first grazed their herds in San Simon Valley about 1867, being attracted by profitable contracts to supply beef to army posts in southeastern Arizona. Overgrazing and erosion have so devastated the valley in recent years that it now sustains only a comparatively small number of cattle.

The discovery of artesian water at San Simon station, on the Southern Pacific Railroad, in 1910 gave a considerable impetus to the agricultural development of the surrounding district by artesian wells.

The lands now actually under cultivation in the entire San Simon Valley, exclusive of the part that is irrigated from the Gila, are

roughly estimated to include, in the Bowie district and on the east slope of the Chiricahua Mountains, 500 acres, in gardens, orchards, and forage crops; in the Rodeo district, 800 to 1,000 acres, in grain sorghums, corn, and beans; in the San Simon district, 2,000 to 2,500 acres, in grain sorghums, sweet sorghums, alfalfa, corn, and winter grains; and in the Artesia district, 800 to 1,000 acres, in gardens, orchards, and forage crops.

SOILS.

The valley fill consists largely of heavy yellow and bluish clays laid down in a lake that occupied the basin in late geologic time. These lake beds are exposed along the Gila Valley and in the northern part of San Simon Valley. Beds of volcanic ash, which settled in the waters of the ancient lake, outcrop at a number of places in the Gila Basin. This material, which is locally but erroneously known as "gyp rock," is soft and easily worked and has been considerably used in the Gila Valley as a building stone.

Overlying the lacustrine deposits in many places are gravels and sands washed down from adjacent mountain sides. Detrital deposits of poorly sorted boulders, gravel, and sand extend as alluvial fans far out into the valley from the mouths of the steeper mountain canyons.

The soils of San Simon Valley thus consist of heavy impervious clays derived from lacustrine deposits, and sandy or gravelly loams derived from material washed down from adjacent mountain slopes.

By reason of the steep gradients and good drainage extensive accumulations of alkali salts do not occur in San Simon Valley. As the drainage basin contains large areas of granitic rocks, however, sodium carbonate is found in the soils and in the artesian waters of the district. One effect of this sodium carbonate, or black alkali, may be to make more difficult the cultivation of the valley bottom clay, which tends to become deflocculated, plastic, and impervious under its influence. The soils of the valley are nearly everywhere fertile under irrigation, but, like soils elsewhere in the semiarid Southwest, they are deficient in nitrogen and humus. There is a considerable area of marshy soil at San Simon Cienaga, where the combined drainage of Cave Creek and upper San Simon Creek has formed a body of black land rich in organic matter, derived from locally abundant vegetation.

VEGETATION.

The native vegetation of San Simon Valley is of high economic utility. Pine forests at higher altitudes, in the Chiricahua and Pinaleno mountains, have afforded local supplies of lumber for many years. A scattering growth of juniper, oak, and walnut below the pines supplies timber and posts. Sycamores and cottonwoods border

the stream courses, and a stunted growth of mesquite, valuable for fuel and posts and for its nutritious pods, covers large areas in the valley bottom.

The valley was originally grassy. Extensive flats covered with sacaton occupied the flood plain, restraining the summer storm waters and effectually preventing erosion. With the advent of cattle, however, the sacaton was overgrazed, and erosion began along cattle trails and wheel ruts and continued until the valley is now drained throughout most of its length by deep and wide barrancas, which have permanently changed the surface. Sacaton pastures are therefore now in large part replaced by bare flats or playas, which, however, during the summer rainy season, produce an abundant crop of "red-root" forage, much relished by cattle. An annual growth of grama and six-weeks grasses covers the higher ground and still supports a considerable number of cattle. In favorable places there is a growth of other forage plants, such as succulent fruit-bearing opuntias, which are eaten by cattle; saltbushes; and even sotol, or Spanish bayonet, the sweet young flower stalks of which are eagerly eaten by range cattle. Alfileria has been introduced and affords winter feed.

On the whole, stockmen regard the San Simon Valley as brushy or "browse" country, rather than as typical grassland.

AGRICULTURAL POSSIBILITIES.

Aside from grazing the types of agriculture practiced or proposed within San Simon Valley are irrigation farming by surface water or by water from artesian wells, dry farming, dry farming supplemented by irrigation with flood water and pumped water, and dry farming supplemented by the use of the adjacent range for grazing.

IRRIGATION FROM STREAM FLOW.

In the Chiricahua Mountains small isolated areas are irrigated by mountain streams, whose effectiveness may hereafter be increased by means of small storage reservoirs. These high irrigated areas are well adapted to raising fruit, especially apples, pears, peaches, plums, prunes, grapes, and bush fruits, as well as grain, forage crops, and many kinds of vegetables. Such products find a ready market in adjacent mining camps, so that the cultivation of these small but well-watered areas is profitable.

ARTESIAN IRRIGATION.

Two distinct artesian districts have been developed within the valley. The older of these districts, which was discovered about 20 years ago, lies on the east slope of Graham Mountain, at an alti-

tude of 3,500 to 4,000 feet. Most of the wells are south of Safford, in washes that lie below the mouths of mountain canyons. Their water supply is apparently derived from mountain run-off caught under the edges of uptilted clay strata, between which the water descends with accumulation of hydrostatic head. These wells yield black alkaline water, and some of them carry a high content of sulphates and common salt. These waters, through their use for irrigation, but more especially through the waste from uncapped wells, have caused the accumulation of injurious amounts of alkali in the soils of some areas. In this district, which is well above the general level, the air circulates freely, so that the cold air flows out and is replaced by warm air from lower levels. The season is therefore about three weeks earlier than in the lower-lying Gila Valley. The soils of this district are sandy loams, which are well adapted to gardening. Alfalfa and other legumes should be grown in this district, for the artesian waters used carry no sediments rich in organic matter and nitrogen, as do the muddy river waters used for irrigation in other parts of the region. Deciduous fruits may be grown here successfully, and also some subtropical fruits that resist frost fairly well, such as certain varieties of figs. Bees and poultry do well, and goats have been ranged in connection with general farming.

The San Simon artesian basin was discovered in 1910. It lies in the valley bottom on the Southern Pacific Railroad, at an altitude of about 3,600 feet. Its soils and climate are probably not so well adapted to fruit growing as some other parts of the valley, but the more abundant artesian and flood-water supplies are favorable to general farming.

Wheat and barley and both grain and forage sorghums grow well in this district, and Sudan grass thrives on even a scant supply of water. Certain varieties of Indian corn, such as Mexican June, do well, and so also does alfalfa, in places where sufficient water can be provided.

Most of the lands in this district must be grubbed and leveled, and reservoirs must be constructed to store good irrigating heads of water from the wells, which generally yield too small a flow to afford a direct supply for irrigation. The use of silos for storing succulent forage will materially assist in developing the live-stock industry in this district. Irrigation farming should as far as possible be carried on in conjunction with stock raising or vice versa. In this way the irrigated forage supplements the wild feed of the range, and the range supplies feeders for the irrigated forage as well as for supplementary wild feed at times of favorable rainfall.

DRY FARMING.

The somewhat uncertain and varying precipitation averages from 10 to 15 inches yearly, and therefore dry farming, if unassisted by supplementary water supplies, can hardly insure satisfactory crops. In unusually favorable seasons, such as the winters of 1904-5 and 1915-16, the rainfall is sufficient to make grain hay or even to mature a crop of wheat or barley.

A favorable succession of summer rains will also make such hardy, quick-growing crops as milo maize, feterita, tepary beans, pumpkins, and Sudan grass. After a few such favorable seasons speculative promotions of so-called dry-farming lands have led to the settlement of lands which later have been found to require a more certain and abundant water supply than is ordinarily afforded by direct rainfall.

Supplementary supplies in areas outside of artesian districts can be obtained occasionally by the use of flood waters and by pumping from wells. Storm waters from higher altitudes, particularly in summer, are diverted and used successfully by the Mexicans and Indians of the Southwest for irrigating quick-growing crops of corn, beans, melons, and squashes, and, especially with the help of small storage reservoirs, should be available in San Simon Valley where the topography is favorable.

In certain areas wells of moderate depth and good capacity may be pumped to advantage. On the edges of the artesian district the hydrostatic head brings deep-well waters nearly to the surface, so that they can be easily pumped. By the use of pumped water at critical times to start or save a crop the dry-land farmer may tide over periods when rainfall fails to afford an adequate supply.

In brief, it may be stated that at altitudes below 5,500 feet in San Simon Valley and elsewhere in Arizona dry farming must be supplemented by a water supply, either from storms, storage reservoirs, or wells.

FARM MANAGEMENT.

Though but few exact data are available upon which to base any very definite recommendations, certain suggestions may be of profit to the new farmer in this district. Where the water supply is comparatively abundant, as at Artesia, in the Chiricahua Mountains, and near San Simon, the farmer's problem is comparatively easy. He can grow a great variety of deciduous fruits, vegetables, and forage crops. But where only the rainfall, supplemented by a scanty supply of ground water, is available the problem becomes difficult and its successful solution requires careful management.

The home vegetable garden.—Of immediate importance to every pioneer family is the area, say about an acre, of fruit trees and garden that may be irrigated by water from the house well, pumped by a windmill or a small oil engine and stored in a small tank or reservoir to maintain an irrigating head. By means of this equipment the table may be supplied every month in the year with a variety of excellent vegetables—in spring and summer with asparagus, corn, beans, pumpkins, squashes, melons, cantaloupes, tomatoes, and deciduous fruits, such as peaches, apples, pears, grapes, and plums; and in winter with beets, cabbage, cauliflower, onions, turnips, radishes, lettuce, and spinach. Some of these products, such as Hubbard squashes, pumpkins, and dried fruits, will keep for a long time. Cabbage may be made into sauerkraut and fruits may be canned. Half the food supply of an ordinary family may thus be obtained from a well-tended vegetable garden that is properly planned, cultivated, and protected from insect pests.

Hardy trees for shade and ornament, such as tamarisks, oleasters, mulberries, cottonwood, and ash, may also be watered from the domestic water supply.

Grain and forage.—In a very wet winter and spring wheat, barley, and oats will make hay, but ordinarily they must be irrigated to make grain. The sorghum grains, such as milo maize, feterita, and Kafir corn, are drought resistant and mature good crops of grain with a minimum supply of water. Certain quick-growing varieties of Indian corn also, if planted early in July, will with necessary irrigation make successful crops.

Sorghum is a standard drought-resistant forage, and Sudan grass, which has been recently introduced, promises to become a hardy and valuable crop. Alfalfa requires abundant irrigation and is not well adapted to dry farming.

To some extent the grains and forages mentioned above may be sold as such, especially barley and baled hay, but new, rough roads, distant markets, and competition with older districts render it more profitable to utilize as far as possible the grain and forage for feeding live stock, for the raising of which the adjacent grazing ranges may be utilized.

Horses and mules.—Horses and mules raised in the adjacent Gila Valley and allowed to range on near-by mountain pastures are well known for stamina and for sound feet and legs. The forage and grain produced on a dry farm combined with range pasture produces excellent work and driving animals.

Beef cattle.—The forage and grain produced on farms in San Simon Valley should be profitably fed to cattle from adjacent ranges, or at least should be used to tide over times of drought and scarcity

on the open range. In many thinly settled locations dry farms and grazing ranges will supplement each other profitably.

Dairy cows.—By means of cheaply constructed pit silos corn and sorghum can be converted into silage for feeding dairy stock, especially at times of drought, when succulent feed is not otherwise to be had. In semiarid districts in New Mexico that somewhat resemble San Simon Valley incomes are earned in this manner and by cooperative cream collecting and hauling.

Hogs.—Milo maize and feterita are a cheap and excellent ration for hogs, having been found superior to alfalfa for this purpose. These drought-resistant crops should therefore provide the dry-farm homestead with its meat supply and should afford a cash return.

Poultry.—Milo maize, feterita, and the miscellaneous seeds and green produce of a dry farm afford good feed for chickens and turkeys. Turkeys in particular are worthy the consideration of settlers in this district. They are native to the region and thrive not only on what may be grown for them but also on wild food, such as red-root weeds and grasshoppers. They command good prices also when they are ready for market.

Bees.—Many plants in the valley afford honey to bees in considerable quantity at certain seasons of the year. The mesquite yields excellent honey, and the mountain foothills during the summer rains carry much wild bloom.

SUMMARY.

In those areas of San Simon Valley that are more abundantly watered by stream flow and by artesian wells a great variety of deciduous fruits and vegetables, as well as grain and forage that may be converted into live-stock products, may be readily grown.

In localities that must depend on rainfall supplemented by pumped reservoir or storm waters a greater diversity of methods and of products will be required for success in agriculture. Among the resources available to the pioneer dry-land farmer in this district are the home garden, which yields a great variety of fruits and vegetables; drought-resistant grain and forage, such as quick-growing varieties of Indian corn, milo maize, feterita, sorghum, and Sudan grass; and live stock, including horses, mules, cattle, dairy cows, hogs, and poultry. Pit silos are essential to success with live stock, especially dairy cows; and the adjacent grazing ranges should be utilized as a source of supplementary feed.

GROUND WATER FOR IRRIGATION IN LODGEPOLE VALLEY, WYOMING AND NEBRASKA.

By OSCAR E. MEINZER.

INTRODUCTION.

LOCATION AND CHARACTER OF VALLEY.

Lodgepole Creek rises in the Laramie Mountains, in Wyoming, and flows eastward and southeastward across the Great Plains to its junction with South Platte River. (See fig. 3.) Its course across the

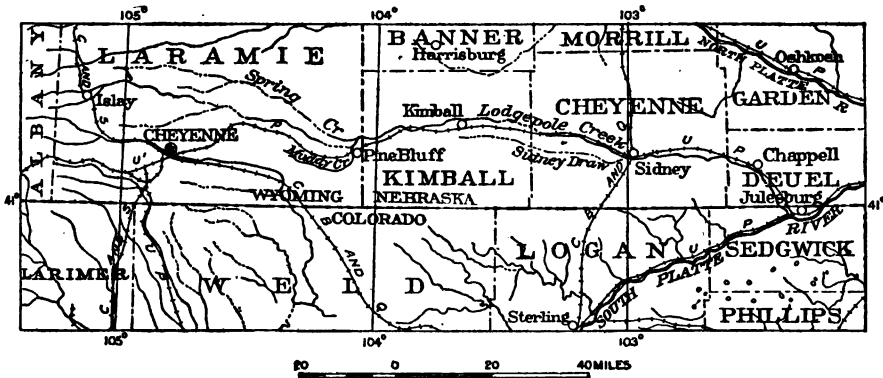


FIGURE 3.—Map showing the drainage basin of Lodgepole Creek and adjacent areas.

plains, not including meanders, is about 165 miles long, of which 65 miles is in Wyoming, 95 miles in Nebraska, and 5 miles in Colorado. Its valley resembles other valleys of the Great Plains in that it is a flat-bottomed, steep-sided trench, formed by stream erosion and later partly refilled by stream sedimentation.

Lodgepole Valley is traversed by the main line of the Union Pacific Railroad from Egbert, Wyo., to the place at which it opens into the broad, flat valley of the South Platte above Julesburg, Colo., and by the Lincoln Highway from Egbert, Wyo., to Chappell, Nebr. It is crossed at Sidney, Nebr., by the Chicago, Burlington & Quincy Railroad, and near the mountains by the Colorado & Southern Railway. Along the Union Pacific line in Lodgepole Valley there are many ranches and several towns, the largest of which is the enter-

prising little city of Sidney. Thirty miles west of Egbert the Union Pacific line passes through Cheyenne, the capital of Wyoming. Above Egbert the valley is settled only at a few cattle and sheep ranches.

PURPOSE AND SCOPE OF INVESTIGATION.

In recent years the residents of Lodgepole Valley have been interested in projects for extending irrigation by pumping shallow ground water or by discovering artesian water, and have repeatedly requested the Federal Government to investigate the subject. It has not been practicable for the Geological Survey to make a thorough study of the ground-water supply of this valley, but in September, 1915, the writer made a brief field investigation, the general results of which are presented in this paper. The data on cost of pumping for irrigation, by H. C. Diesem (pp. 67-69), were generously furnished by the division of irrigation investigations, Office of Public Roads and Rural Engineering, United States Department of Agriculture.

PHYSIOGRAPHY.

The drainage basin of Lodgepole Creek comprises a long, narrow belt between the much larger basins of the North Platte and the South Platte, from which it is separated by inconspicuous divides. It is about 175 miles long, $12\frac{1}{2}$ miles in average width, and approximately 2,200 square miles in area.¹ It includes narrow segments of two very distinct physiographic provinces, the Laramie Mountains and the Great Plains. The mountain segment is about 13 miles long and 5 miles in average width, and comprises about 65 square miles, or 3 per cent of the total drainage basin. All the rest of the drainage basin is in the Great Plains. The mountain segment ranges in altitude from about 7,000 to 8,000 feet above sea level; the upland surface of the plains segment from about 7,000 feet near the mountain front to less than 4,000 feet near the mouth of Lodgepole Creek.

The steep-walled, flat-bottomed valley that the creek has cut into the generally smooth surface of the plains averages about $1\frac{1}{2}$ miles in width and ranges in depth from less than 100 feet to fully 250 feet.

The flood plain of the creek is bordered by terraces that stand at different elevations. In the upper part of the valley there are two rather definite terrace levels. In the vicinity of Ariosa and Pole Creek ranches the first terrace is about 15 feet above the stream, or 10 feet above the flood plain, and the second terrace is 30 to 50 feet above the stream. Below Pinebluff the second terrace is about 65 feet above the stream, and is well marked throughout most of Kimball County. In the vicinity of Sidney there is but one distinct terrace, and it is only 10 to 20 feet above the flood plain.

The upland surface of the Great Plains is interrupted by two prominent escarpments, about 250 feet high, one near Islay and the other

¹ Price, D., D. Nebraska Board of Irrigation, Highways, and Drainage Tenth Bienn. Rept., p. 37, 1914.

near Pinebluff. These escarpments trend transverse to the course of the valley and face the west. On the west side of each is a low, flat plain that coincides in level with the floor of Lodgepole Valley and forms essentially an expanded part of the valley. The upland on the east side of each escarpment is a part of the general surface of the Great Plains, which slopes gently toward the east. The descent from the upland surface east of the Islay escarpment to the lowland surface on the west side of the Pinebluff escarpment is for the most part gradual, but there is an east-facing escarpment of some prominence in the vicinity of Egbert. These escarpments appear to be erosion features in the nature of hogbacks. The valley is deepest and narrowest where Lodgepole Creek cuts through the upland back of the Islay escarpment.

GEOLOGY.

Lodgepole Valley is underlain by sedimentary formations of great aggregate thickness, which rest on pre-Cambrian granite and other crystalline rocks. The following generalized section of these formations in the vicinity of the Laramie Mountains in southeastern Wyoming is given by Darton and Siebenthal.¹ The Ogalalla formation, which occurs extensively along Lodgepole Valley, has been added to the section.

Generalized section of formations that outcrop in the vicinity of the Laramie Mountains and extend beneath the Great Plains.

[After N. H. Darton and C. E. Siebenthal.]

System.	Formation.	Character of rocks.	Thickness, in feet.
Tertiary.....	Ogalalla formation..	Poorly assorted deposits of clay, sand, and gravel with much calcareous cement.	0-300
	Arikaree formation..	Sand, gravel, and boulder beds, with local limestone lens.	200-250
	Brule clay.....	Massive pinkish sandy clay, with gravelly streaks.	250
	Chadron sandstone..	Massive brown sandstone, merging into sand and gravel.	20-100
Cretaceous.....	Fox Hills sandstone.	Gray sandstone and sandy shale.....	700+
	Pierre shale.....	Dark-gray shale with thin beds of sandstone....	5,000
	Niobrara limestone..	Impure chalky limestone and gray limy shale; massive gray limestone at base.....	325-400
	Benton shale.....	Gray shale and some sandstone.....	700-1,000
	Cloverly formation..	Hard gray sandstone and purple to gray sandy clay. [Includes Dakota sandstone at top.]	70-100
Cretaceous or Jurassic...	Morrison formation..	Massive pale green to maroon shale with thin limestones and sandstones.	150-200
Jurassic.....	Sundance formation.	Buff slabby sandstone and sandy gray shale....	30-60
Triassic or Permian.....	Chugwater formation	Red sandy shale and fine-grained sandstone, and beds of gypsum near base.	80-1,000
Carboniferous.....	Casper formation....	Gray to red sandstone, gray to purple limestone, and red shale. Gray to reddish brown sandstone and conglomerate at base.	800-1,000
Pre-Cambrian.....		Granite, gneiss, schist.....	

^a This formation is not found near the Laramie Mountains but occurs extensively on the plains adjacent to Lodgepole Valley.

¹ Darton, N. H., Blackwelder, Elliot, and Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Laramie-Sherman folio (No. 173), 1910.

Below the Great Plains the formations older than the Tertiary nearly horizontal, but in a narrow belt along the edge of the mountains they are bent sharply upward and in some places overturned, faulted, or complexly warped. The Tertiary beds are nearly horizontal in this region, not only below the Great Plains, where they completely conceal the older formations, but also near the mountains where to some extent they overlap the deformed and eroded edges of the older formations. In some parts of western Nebraska the Cretaceous strata younger than the Pierre shale are absent and the Tertiary beds rest on this shale.¹

As the Tertiary formations are important in connection with the ground water of this region, they will be briefly described.

The Chadron sandstone, which lies at the bottom of the Tertiary system, crops out near the Laramie Mountains, where it is a bed 20 to 40 feet thick overlapping the older formations.² Eastward it passes under the Brule clay, but whether it is a continuous formation in the vicinity of Lodgepole Valley is not known.

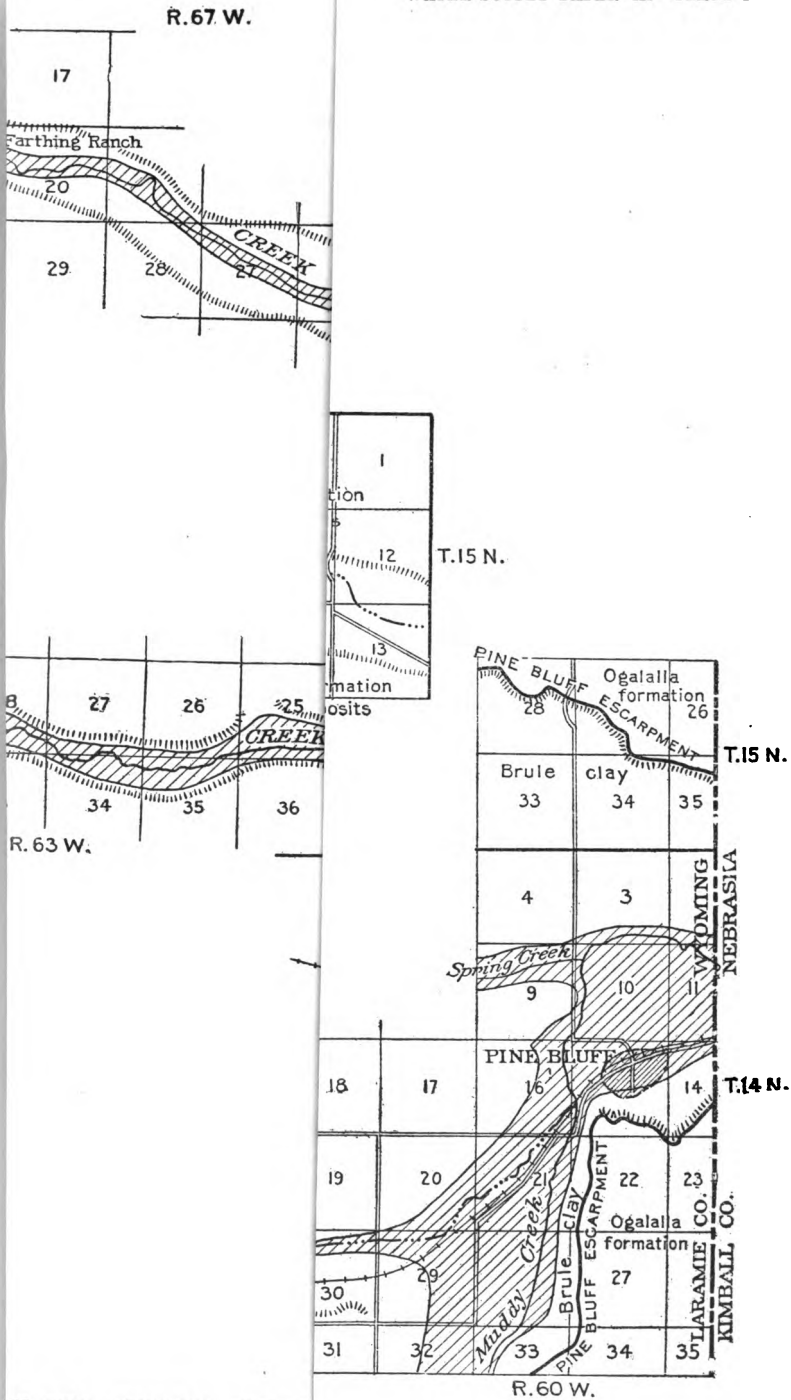
The Brule clay is a moderately hard, compact, brittle, silty clay, prevailing pale pinkish or flesh color. It has indistinct but regular bedding planes, and where it is weathered it is much jointed and broken into more or less cubical blocks. This is the formation that many of the drillers in Lodgepole Valley call "hardpan."

The Brule clay is at or near the surface over most of the Islay lowland between the Islay escarpment and the older formations that fringe the mountains (Pl. IV). It forms the lower part of this escarpment, outcropping to a height of about 70 feet in a locality southeast of the Van Tassell ranch, but it passes beneath the upland east of the escarpment and beneath the valley 2 or 3 miles east of the Heasman ranch. It again appears in the vicinity of Egbert, 45 miles farther east, where it is reached by the Egbert Railway well (p. 56) and comes to the surface at the base of the eastward facing escarpment (Pl. IV). It is at or near the surface over a considerable area of the Pinebluff lowland, from the Egbert escarpment to the Pinebluff escarpment. It crops out to a height of about 150 feet in the Pinebluff escarpment south of the village of Pinebluff but passes beneath the upland plain east of this escarpment. This formation apparently underlies the valley at no great depth throughout Nebraska, a distance of over 90 miles, and it is exposed at many places in the lower parts of the valley walls.

As the base of the Brule clay is not exposed except near the mountains and has rarely been reached in drilling in this region, the total thickness of the formation is not definitely known. Thicknesses of

Darton, N. H., Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U. S. Geol. Survey Prof. Paper 17, pl. 11, 1903.

² Darton, N. H., Blackwelder, Elliot, and Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Laramie-Sherman folio (No. 173), p. 10, 1910.



TY, WYO., SHOWING GEOLOG

250 to more than 600 feet have been observed by Darton¹ in adjacent parts of Nebraska and Wyoming. In a well 400 feet deep at Julesburg, Colo., 160 feet of "yellow clay," which is probably Brule clay, was found below the alluvial gravels. Below this clay there was a few inches of sand, below which blue shale—probably a Cretaceous formation—was penetrated 200 feet.

The Arikaree formation consists mainly of soft, fine-grained, light gray sandstone containing numerous large concretions that are very characteristic.² It appears in typical character in the Egbert escarpment and for some miles west of Egbert, outcropping in the valley walls at least as far as the middle of T. 15 N., R. 64 W., and in tributary ravines a few miles west of Burns (Pl. IV). It is penetrated by many wells in the valley and on the upland from the vicinity of Egbert to the vicinity of the Pole Creek ranch. It is generally mantled by gravelly deposits, which west of the Pole Creek ranch form the entire valley wall and completely conceal the typical sandstone of the Arikaree formation. The Arikaree formation is not seen in the Pinebluff escarpment, nor at any point farther east near Lodgepole Valley. It is not found in typical character in the Islay escarpment, but the gravelly beds overlying the Brule clay are believed by Darton³ to represent a coarse phase of the Arikaree. The fine-grained concretionary sandstone appears to be merely a lens between the Brule clay and overlying gravelly deposits.

The Ogallala formation, which lies on the Brule or the Arikaree, consists of irregular beds of poorly assorted clayey, sandy, and gravelly materials, and much calcareous cement. The less cemented parts are pinkish, but the calcareous beds are more nearly white or cream-colored. This formation underlies extensive areas of the Great Plains. It is exposed in the upper 100 feet of the Pinebluff escarpment and in the upper parts of the valley walls generally from Pinebluff nearly to the lower end of the valley. In the entire region adjacent to Lodgepole Valley east of Pinebluff, so far as known, the Ogallala formation underlies the upland plain and rests on the Brule clay.

In the Islay escarpment southeast of the Van Tassel ranch the Brule clay is overlain by 70 feet of clean arkosic conglomerate, above which is about 40 feet of cemented gravelly beds, which resemble somewhat the Ogallala formation but which are believed by Darton to be for the most part a gravelly phase of the Arikaree. Three miles below the Heasman ranch the entire valley wall, 250 feet high, appears to

¹ Darton, N. H., Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U. S. Geol. Survey Prof. Paper 17, pp. 37-40, 1903; and Darton, N. H., Blackwelder, Elliot, and Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Laramie-Sherman folio (No. 173), 1910.

² An excellent description of this sandstone is given in Prof. Paper 17, pp. 25-29.

³ Darton, N. H., Blackwelder, Elliot, and Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Laramie-Sherman folio (No. 173), p. 11, 1910.

consist of poorly assorted gravelly and clayey beds—evidently coarse outwash from the near-by mountains. These gravelly deposits extend eastward indefinitely but become much thinner in the vicinity of Burns and Egbert, where at many places they rest with sharp contrast on the very different beds of the typical Arikaree formation.

The valley is underlain through almost its entire length by recent alluvium, which generally includes considerable coarse, clean gravel. The deposit is, however, not thick, the well records indicating 10 to 15 feet at Pinebluff; 35 to 50 feet or more at Bushnell, Kimball, and Potter; 25 feet at Sidney; 20 to 30 feet at Zunol; 15 to 20 feet at Lodgepole; 35 feet at Chappell; and 40 feet at Julesburg. On much of the Islay lowland and the lowland between Egbert and Pinebluff the alluvium is absent or very thin. At some places below Egbert the creek has cut into the Brule clay.

A gravelly deposit that is probably intermediate in age between the Ogalalla formation and the recent alluvium covers a considerable area of lowland west of Islay, and gravels of intermediate age are found also on the terraces throughout the valley.

PRECIPITATION.

The following table, compiled from the published records of the United States Weather Bureau to 1909, shows that Lodgepole Valley is in the semiarid region, in which dry farming is practiced but in which production can be greatly increased by irrigation. The precipitation is greatest in spring and summer and least in fall and winter. It is no doubt somewhat greater in the mountains than on the plains, but on the plains it does not decrease very much from east to west. The precipitation in the valley is probably not much different from that on the adjacent upland.

Average monthly precipitation, in inches, at points in or near Lodgepole Valley.

[Compiled from the published records of the U. S. Weather Bureau to 1909.]

Place.	Ap- prox- imate length of rec- ord.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	<i>Years.</i>												
Cheyenne.....	39	0.38	0.54	0.98	1.73	2.48	1.65	2.06	1.47	1.00	0.71	0.41	0.39
Pinebluff.....	9	.16	.62	1.16	2.51	2.51	1.88	2.58	1.48	1.00	.73	.31	.45
Kimball.....	19	.45	.66	1.09	2.08	2.70	2.12	2.71	1.42	.91	.63	.42	.54
Sidney and Lodge- pole.....	29	.46	.59	.91	1.80	2.75	1.73	2.51	1.91	1.04	.74	.25	.38

• Lodgepole since 1894.

Lowest, highest, and average annual precipitation at points in or near Lodgepole Valley.

Place.	Number of complete years covered by the record.	Lowest.	Highest.	Average.
		<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>
Cheyenne.....	37	5.04	22.68	13.80
Pinebluff.....	8	10.90	26.24	15.29
Kimball.....	15	11.13	25.59	15.74
Sidney.....	20	7.70	26.92	15.07

SURFACE WATERS.

The north and south forks of Lodgepole Creek head in a number of branches in the Laramie Mountains and unite on the Islay lowland at the Van Tassell ranch. Thence the creek leads to South Platte River, into which it discharges about 5 miles above Julesburg, Colo. The length of the creek from its sources to its mouth is about 175 miles if measured along the main trend of the valley but much more if measured along its intricately meandering channel. In its long course through the Great Plains it receives storm waters from innumerable gullies and the underflow from numerous tributary valleys and no doubt from the adjacent uplands, but only a few of its tributaries carry a perennial flow of surface water, and these are small.

Lodgepole Creek does not persistently decrease in volume downstream, like most desert streams, nor does it persistently increase, like most streams in humid regions, but its flow increases and decreases in alternating reaches and in three reaches its channel is normally dry. No gaging station has been maintained on Lodgepole Creek, but current-meter measurements have frequently been made at many places by the United States Geological Survey and the State engineer of Nebraska, the results of which are given in the table on page 46. At the time the valley was examined, in September, 1915, the flow of the creek was measured or estimated at the points indicated below. The differences in flow were due to some extent to diversions that were not specifically noted.

About half a mile above the Heasman ranch, where the creek leaves the Islay lowland and enters the gorgelike valley, its flow, as measured with a current meter, was about $7\frac{1}{2}$ second-feet, most of the water being contributed by branches that head in the mountains and little gain or loss being made on the Islay lowland. From this point to the diversion dam, about 14 miles downstream, in the NE. $\frac{1}{4}$ sec. 36, T. 16 N., R. 67 W. (see Pl. IV), the flow appeared to decrease slightly. At this dam the surface water and presumably nearly all the underflow was diverted, the total being probably somewhat less than the flow above the Heasman ranch. For a short distance below

the dam the channel was dry, but at the Ariosa and Pole Creek ranches the flow was fully 1 second-foot. A few miles below the Pole Creek ranch, however, the stream disappeared and the channel was dry for a distance of nearly 10 miles.

From a springy area near the west margin of sec. 26, T. 15 N., R. 64 W., to a point north of Egbert, in sec. 13, T. 14 N., R. 62 W., a distance of about 15 miles, there was a continuous stream, which, however, probably nowhere carried more than 1 or 2 second-feet. From Egbert to its junction with Muddy Creek, just southwest of Pinebluff, a distance of a little more than 10 miles, Lodgepole Creek was entirely dry, and the fact that its channel in this stretch is cut through the alluvium into the Brule clay indicates that there is but little underflow here.

At Pinebluff, a short distance west of the Wyoming-Nebraska State line, Lodgepole Creek is replenished by two tributaries, both of which rise on the Great Plains. In September, 1915, Muddy Creek, the south-side tributary, discharged approximately 1 second-foot, and Spring Creek, the north-side tributary, discharged approximately 3 second-feet into the channel of Lodgepole Creek. Considerable underflow along these streams also entered Lodgepole Creek, so that 2 miles below the mouth of Spring Creek, at the road half a mile east of the State line, the measured flow of Lodgepole Creek was about 6 second-feet.

In September, 1915, Lodgepole Creek contained flowing water from its junction with Muddy Creek nearly to Dix, a distance of about 33 miles. It was intercepted by the Kimball reservoir, in T. 15 N., R. 57 W., but some water was escaping under the dam of this reservoir. Half a mile below the dam its flow was fully 2 second-feet, and at Kimball it had increased to more than 6 second-feet, as measured with a current meter. Farther downstream, at the west margin of sec. 25, T. 15 N., R. 55 W., its flow decreased to about 3 second-feet, and at the west margin of sec. 27, T. 15 N., R. 54 W., to about 1 second-foot, and before reaching the road that extends northward from Dix the channel became entirely dry.

The channel was dry from the vicinity of Dix to a point below Potter, a distance of about 12 miles, but this part of the valley is underlain by gravel and no doubt carries considerable underflow.

The stream reappeared in sec. 9, T. 14 R., R. 52 W., and thence flowed without interruption so far as observed at least to the Colorado State line. It was reported that near its mouth the creek again sinks, at least in some seasons, but this report was not verified. About midway between the east and west margins of sec. 2, T. 14 N., R. 52 W., 2 or 3 miles below the point where the creek reappeared, its flow was somewhat more than 4 second-feet, as measured with a current meter, and at Sidney it was about 6 second-feet. Below

Sidney it showed some irregularities, but in the vicinity of Lodgepole it was enlarged to perhaps 10 second-feet by contributions from several springs and from the underflow of tributaries entering the valley from both sides. Farther downstream the flow decreased, and a float measurement made about a mile west of Chappell indicated that it was about 5 second-feet. Still farther downstream, however, it increased considerably, and in sec. 12, T. 12 N., R. 45 W., not far from the Colorado State line, a float measurement indicated that it was about 15 second-feet. Apparently the amount of underflow also increased considerably in the lower part of the valley. According to older reports the creek is sometimes dry in the lower part of T. 14 N., R. 51 W., largely because of the diversion of water for irrigation,^b and near Colton, where the water sinks.^c The data given in the following table show that the creek is sometimes dry or very small at other places, but these minor fluctuations are in large part the result of irrigation:

Miscellaneous measurements of Lodgepole Creek, Wyo.-Neb.^c

Locality.	Date.	Flow, in second-feet.
NE. $\frac{1}{4}$ sec. 23, T. 16 N., R. 60 W. ^d	Sept. 17, 1915	7.45
Wyoming-Nebraska State line.....	Aug. —, 1895	3.56
Do.....	May 2, 1904	4.30
West margin sec. 12, T. 14 N., R. 50 W. ^d	Sept. 21, 1915	6.09
One mile east of Wyoming-Nebraska State line.....	May 2, 1904	4.60
Sec. 12, T. 14 N., R. 50 W.....	July 30, 1901	2.90
Sec. 8, T. 14 N., R. 58 W.....	May 3, 1904	34.50
Sec. 3, T. 14 N., R. 58 W.....	Aug. 8, 1900	6.23
Sec. 2, T. 14 N., R. 58 W.....	May 26, 1900	9.23
Do.....	June 3, 1903	10.1
Sec. 33, T. 15 N., R. 57 W.....	Aug. 10, 1900	12.34
Sec. 31, T. 15 N., R. 57 W.....	June 1, 1903	15.8
Sec. 33, T. 15 N., R. 57 W.....	June 2, 1903	12.8
Sec. 36, T. 15 N., R. 57 W.....	May 25, 1900	4.75
Sec. 31, T. 15 N., R. 56 W.....	July 2, 1902	10.5
Do.....	June 1, 1903	12.5
Do.....	July 23, 1903	.5
West line sec. 33, T. 15 N., R. 56 W.....	Apr. 28, 1904	14.4
Do.....	Apr. 30, 1904	12.4
Do.....	May 5, 1904	48.2
Sec. 27, T. 15 N., R. 56 W.....	July 31, 1901	6.2
Four miles west of Kimball.....	Aug. 9, 1899	7.43
Three miles below sec. 31, T. 15 N., R. 56 W.....	July 23, 1903	7.5
Three miles west of Kimball.....	Sept. 8, 1904	8.6
Sec. 35, T. 15 N., R. 56 W.....	May 27, 1903	31.3
Sec. 26, T. 15 N., R. 56 W.....	Apr. 25, 1908	16.6
Do.....	May 29, 1903	81.0
Sec. 25, T. 15 N., R. 56 W.....	July 2, 1902	7.5
West line sec. 25, T. 15 N., R. 56 W.....	July 23, 1903	7.4
One mile west of Kimball.....	Sept. 10, 1900	1.29
Do.....	Aug. 9, 1899	2.41
Above Polly Dam, sec. 30, T. 15 N., R. 56 W.....	Sept. 10, 1900	2.44
Below Polly Dam at bridge.....	do.....	1.13
Sec. 30, T. 15 N., R. 55 W.....	Dec. 7, 1904	25.6
Kimball.....	May 26, 1896	4.5
Do.....	Sept. 12, 1900	4.92
Do.....	Sept. 15, 1900	1.14
Do.....	Sept. 18, 1900	4.3
Do.....	June 2, 1902	5.6
Do.....	June 15, 1904	2.1
Do.....	Sept. 6, 1904	13.4

^a Darton, N. H., Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 4, p. 770, 1898.

^b Price, D. D., Nebraska Board of Irrigation, Highways, and Drainage Tenth Bienn. Rept., p. 36, 1914.

^c See Hoyt, J. C., and Wood, B. D., Index to the hydrographic progress reports of the United States Geological Survey, 1888 to 1903, p. 127, 1906; and Price, D. D., Hydrographic report of Nebraska, 1914, pp. 333-335.

^d Measurements by O. E. Mainzer.

Miscellaneous measurements of Lodgepole Creek, Wyo.-Nebr.—Continued.

Locality.	Date.	Flow, in second-feet.
West line sec. 29, T. 15 N., R. 55 W.	July 24, 1903	6.6
Do.	Oct. 30, 1903	15.5
Do.	Nov. 7, 1903	21.6
Do.	Nov. 16, 1903	20.4
Do.	May 4, 1904	20.5
Kimball.	Sept. 23, 1915	6.2
Three-fourths mile east of Kimball.	Aug. 11, 1899	2.09
Sec. 23, T. 15 N., R. 55 W.	Aug. 9, 1900	6.34
Sec. 26, T. 15 N., R. 55 W.	Apr. 24, 1903	12.64
Do.	July 24, 1903	4.6
Sec. 26, T. 15 N., R. 55 W.	Apr. 25, 1902	12.0
West line sec. 30, T. 15 N., R. 54 W.	July 24, 1903	.0
West line sec. 3, T. 14 N., R. 52 W.	July 25, 1903	3.2
Near west margin S.E. $\frac{1}{4}$ sec. 2, T. 14 N., R. 52 W.*	Sept. 23, 1915	4.20
Center sec. 8, T. 14 N., R. 51 W.	July 25, 1903	3.5
Do.	Apr. 27, 1904	8.62
Sec. 9, T. 14 N., R. 51 W.	July 1, 1901	5.6
Do.	July 25, 1903	3.8
Center sec. 9, T. 14 N., R. 51 W.	Apr. 27, 1904	6.62
Sec. 10, T. 14 N., R. 51 W.	June 18, 1903	5.4
Do.	July 25, 1903	3.8
Center sec. 10, T. 14 N., R. 51 W.	Apr. 27, 1904	7.25
Sec. 14, T. 14 N., R. 51 W.	May 17, 1900	2.34
Do.	Aug. 17, 1900	2.35
East line sec. 14, T. 14 N., R. 51 W.	July 25, 1903	.0
Sec. 15, T. 14 N., R. 51 W.	do.	2.9
Sec. 20, T. 14 N., R. 50 W.	Dec. 7, 1904	4.4
Sidney.	July 1, 1901	6.7
Sec. 33, T. 14 N., R. 49 W.	May 15, 1900	3.86
Do.	Aug. 14, 1900	6.42
Three miles east of Sidney.	May 15, 1899	10.95
One-half mile west of Jones dam, sec. 34, T. 14 N., R. 49 W.	May 15, 1900	6.26
Sec. 29, T. 14 N., R. 48 W.	July 2, 1901	4.0
Sec. 31, T. 14 N., R. 47 W.	May 15, 1900	2.6
Do.	Aug. 16, 1900	2.5
Sec. 29, T. 14 N., R. 47 W.	July 2, 1901	2.2
Sec. 36, T. 14 N., R. 47 W.	Apr. 13, 1902	4.0
Lodgepole station.	Oct. 8, 1900	2.12
Sec. 31, T. 14 N., R. 46 W.	July 3, 1901	3.4
East line sec. 31, T. 41 N., R. 46 W.	Sept. 8, 1904	3.3
Sec. 3, T. 13 N., R. 46 W.	May 21, 1900	2.26
Sec. 2, T. 13 N., R. 46 W.	Aug. 22, 1900	2.85
Chappell.	Oct. 18, 1900	3.11
Sec. 36, T. 13 N., R. 45 W.	Aug. 7, 1900	3.12
Sec. 3, T. 12 N., R. 45 W.	Aug. 10, 1900	1.34
Sec. 12, T. 12 N., R. 45 W.	May 22, 1900	1.33

* Measurements by O. E. Meinzer.

According to State Engineer Price, Lodgepole Creek is noted for its early spring floods, due to melting snows and heavy spring rains. The largest flow that has been measured was 48 second-feet, but Mr. Price states that during short flood stages the flow greatly exceeds this amount.¹ In the upper part of its course, where it receives its water from the mountains, the creek fluctuates greatly in volume, but these fluctuations have little effect on the flow in the lower parts of the stream. Near Egbert the flood waters sink rapidly into the gravels, and the freshets rarely get far except in winter, when the ground is frozen. At no time during the summer of 1915 did the water flow across the road leading northward from Egbert. It is reported that at Potter no water flows in the creek bed even during heavy rains, and the infrequency of floods is indicated by the fact that there is a well on the bed of the creek and a house hardly 5 feet higher.

¹ Price, D. D., op. cit., p. 37.

WATER IN ALLUVIAL GRAVEL AND SUBJACENT BEDS.**OCCURRENCE.**

The alluvial gravel in Lodgepole Valley and the porous or cavernous parts of the formations immediately under the gravel form a reservoir in which is stored a part of the water that falls as rain or snow in the valley. The alluvial gravel is generally clean and coarse and therefore can hold much water and yield it freely, as is shown by records of such wells as the city wells of Kimball, Sidney, and Chappell, the railroad well at Chappell, and the irrigation well of Mr. Gus Forsling. (See pp. 56-61.) Its total capacity as a reservoir is, however, limited by the shallowness of the alluvial deposit, especially in the Islay and Pinebluff lowlands.

In most of the valley below Egbert the alluvial gravel is underlain by Brule clay, locally known as "hardpan." In general this formation is a poor water bearer, but at many places where it underlies the gravel it appears to yield water very freely, as is indicated by the records of the city well at Pinebluff, the railroad wells at Egbert and Pinebluff, the Campbell irrigation well, and other wells mentioned on pages 56-61. This capacity to yield water freely appears to be due to joints or other crevices in the clay where it lies below the alluvial gravel. The storage capacity of these crevices is, however, probably not great, so that the clay is dependent on the overlying gravel for-reserve supplies. Where the gravel deposit is very thin, as in the Pinebluff lowland and along the margins of the valley generally, the Brule clay is not always a reliable source of water, and some wells that end in it yield only small amounts.

Between Egbert and the Pole Creek ranch the alluvial gravel is underlain by sandstone of the Arikaree formation, which contains much water but which, on account of its fine grain and its incoherence, does not part with its water so freely as the gravel or the vesicular clay. By using coarse screens, cleaning out the wells thoroughly, and inserting gravel if necessary, large supplies could probably be obtained from this formation.

The sections of the city and railroad wells at Potter suggest that the water-bearing beds which there lie below the alluvium may belong to the Ogallala formation. Both these wells yield the large quantities of water that would be expected from wells that end in gravel beds of the Ogallala formation.

THE WATER TABLE.

The underground reservoir formed by the gravel, sand, and vesicular clay is filled with water about to the level at which the water stands in wells. The water table, or surface below which the deposits are saturated, is, of course, not entirely level but slopes downstream with approximately the same grade as the valley floor, and also no

doubt generally slopes from the margins of the valley toward the stream channel. The average grade of the water table is about 27.5 feet per mile from the junction of the north and south forks of Lodgepole Creek to the Wyoming-Nebraska State line, 16 feet per mile in Kimball County, 15 feet per mile in Cheyenne County, and 15 feet per mile in Deuel County.

The depth to the water table is one of the most important factors determining the lift and therefore the cost of pumping. The water table comes practically to the surface along those parts of Lodgepole Creek in which water is flowing, as is indicated by springs, wet ground, and salt grass. It generally passes beneath the surface on each side of the creek and also in the reaches where the creek is dry.

According to the rapid survey made in September, 1915, the floor of Lodgepole Valley, including the terraces, covers about 150,000 acres. In about 60,000 acres of this area the depth to the water table is less than 25 feet, and in most of the rest it is less than 50 feet. The area in which the water table is less than 25 feet below the surface is distributed about as follows: Laramie County, 15,500 acres; Kimball County, 10,500 acres; Cheyenne County, 23,500 acres; Deuel County, 10,500 acres.

In the dry reach below the Pole Creek ranch the depth to the water table increases for several miles down the valley and then gradually decreases. On September 14, 1915, the water in a well in the NE. $\frac{1}{4}$ sec. 20, T. 15 N., R. 64 W., stood 18 feet below the surface, or about 8 feet below the level of the stream channel, and that in a well in the SE. $\frac{1}{4}$ sec. 26, T. 15 N., R. 64 W., stood 17 feet below the surface, or about 7 feet below the level of the dry channel. Along the channel in sec. 26 there are trees that evidently reach ground water, and at the east margin of the section the ground water reappears in springs.

In September, 1915, the second dry reach began in sec. 13, T. 14 N., R. 62 W., and it was reported that in only one summer in recent years has the stream reached the east margin of this section except during occasional freshets. In a dug well, 26 feet deep, in the NW. $\frac{1}{4}$ sec. 18, T. 14 N., R. 61 W., the water stood 23 feet below the surface, or about 13 feet below the dry channel. In a dug well near the northeast corner of sec. 30, T. 14 N., R. 61 W., only slightly above the valley floor, the water stood 25 feet below the surface. In a drilled well in the SW. $\frac{1}{4}$ sec. 10, in the same township, the water stood 46 feet below the surface. In a drilled well in the NE. $\frac{1}{4}$ sec. 21 the water stood 55 feet below the surface, or about 30 feet below the level of the dry channel due south. In a well near the east margin of sec. 26 the water appeared to be about 30 feet below the dry channel. Down the valley from Tracy siding the ground water apparently comes nearer the surface; in a well in the NE. $\frac{1}{4}$ sec. 32, T. 14 N., R. 60 W., in September, 1915, it was only 9.5 feet below

the surface, and along the valley of Muddy Creek it appeared at the surface.

The third dry reach began east of the east margin of sec. 29, T. 15 N., R. 54 W. In a drilled well in the NW. $\frac{1}{4}$ sec. 26, the water stood 35 feet below the surface, or about 23 feet below the dry channel. In a well in the SW. $\frac{1}{4}$ sec. 30, T. 15 N., R. 53 W., the water stood 17 feet below the surface, or only about 11 feet below the dry channel. In a well near the southwest corner of sec. 30, about 30 feet above the dry channel, the depth to water was reported to be 38 feet, and on still higher ground, about a mile farther south, the depth to water was reported to be about 100 feet. In a drilled well in the NW. $\frac{1}{4}$ sec. 36, T. 15 N., R. 54 W., on the south side of the road about 2 feet below the level of the railroad, the depth to water was 57 feet. In a well in the NW. $\frac{1}{4}$ sec. 2, T. 14 N., R. 53 W., about 55 feet above the dry channel due north, the depth to the water was reported to be about 100 feet, or 45 feet below the level of the dry channel. The water in a well near the middle of the east margin of sec. 2, on ground 15 or 20 feet lower, was reported to be 60 feet below the surface, and in a well a mile farther east 49 feet below the surface. In a well drilled in the NE. $\frac{1}{4}$ sec. 1 the water stood 32 feet below the surface, or fully 20 feet below the level of the dry channel and 40 feet below the first terrace. A well in the NW. $\frac{1}{4}$ sec. 6, T. 14 N., R. 52 W., was dry at a level 18 feet below the stream channel. Just west of Potter, where the railroad crosses the creek, the water in an excavation made a few years ago was found to be 22 feet below the level of the dry channel. In the city well at Potter the water was 33.5 feet below the surface, or about 12 feet below the level of the stream channel due south. In a well 30 feet deep in the stream channel due south of the Potter city well the depth to water was said to be 14 feet. A little more than a mile farther down the valley the ground water comes to the surface.

The sinking of the water table to considerable depths below the surface and the consequent drying up of the stream in several parts of the valley may be due to irregularities in the grade of either the valley or the water table. Irregularities in the grade of the water table could be produced by differences in the quantity of water contributed to the underground supply or in the porosity of the alluvium. The water table will be high where the inflow is great and also where the ground water is more or less impounded by relatively impervious alluvium. Difference in inflow is certainly one of the causes of variation in level, but the interrelations of the various factors can not be determined until an accurate profile of the stream channel is made.

On account of the slope of the water table the ground water moves constantly but slowly downstream. The rate of movement depends

on the porosity of the material and on the grade of the water table. According to underflow measurements that have been made by the United States Geological Survey, the average rate of movement in the general direction of the valley is 8 feet per 24 hours in the valley of Arkansas River near Garden City, Kans.,¹ 17 feet in the valley of the South Fork of Republican River near St. Francis, Kans.,² and 6.4 feet in the valley of the South Platte near Ogalalla, Nebr.³ The slope of the water table at the localities where the measurements were made amounted to 7.5 feet per mile in the Arkansas Valley and 10.7 feet in the valley of the South Fork of the Republican. The alluvial gravels in Lodgepole Valley probably conduct water as freely as the similar gravels in the valleys where the underflow measurements were made and the grade of the water table is somewhat steeper (p. 48). Where the ground-water supply is replenished to such an extent that the underground reservoir overflows, the surplus water is carried away as a surface stream at a rate much more rapid than that of the underflow.

SOURCE AND DISPOSAL.

A rough balance between intake and discharge of ground water is maintained naturally in Lodgepole Valley from year to year. The underground supply in the valley is replenished by (1) downward percolation of water that falls directly on the valley as rain or snow; (2) downward percolation of water that reaches the valley in permanent streams or in freshets; (3) underflow from the alluvial deposits of tributary valleys; and (4) percolation from the water-bearing members of the Ogalalla, Arikaree, and other formations that underlie the uplands adjacent to the valley. Practically all this water is derived from the precipitation on the drainage basin of Lodgepole Creek. The underground supply is diminished by (1) evaporation where the water table is near the surface, (2) transpiration of plants, (3) seepage into the creek bed, and (4) underflow into the South Platte Valley. The water that seeps into the creek bed either returns to the atmosphere by evaporation and transpiration, flows into the South Platte, or percolates back into the underground reservoir. Considerable surface water that reaches the valley flows through to the South Platte because the underground reservoir of the valley is full or so nearly full that but little water can percolate into it.

If ground water is pumped in large quantities, the water table will be somewhat lowered. As a result, there will be smaller loss by

¹ Slichter, C. S., The underflow in Arkansas Valley in western Kansas: U. S. Geol. Survey Water-Supply Paper 153, p. 5, 1906.

² Wolff, H. C., The utilization of the underflow near St. Francis, Kans.: U. S. Geol. Survey Water-Supply Paper 258, p. 119, 1911.

³ Slichter, C. S., and Wolff, H. C., The underflow of the South Platte Valley: U. S. Geol. Survey Water-Supply Paper 184, p. 11, 1906.

evaporation, transpiration, and seepage into the creek, and greater replenishment from stream water that would otherwise reach the South Platte and from ground water on both sides of the valley. Thus a new balance will tend to become established between the intake and the withdrawal, including the withdrawal by pumping. If the pumpage in any section of the valley is increased beyond the limits of possible adjustment, there will, of course, be progressive depletion of the supply. The total quantity of water utilized, and hence the total acreage of land irrigated, can be increased by pumping from wells, because pumping will eliminate a part of the natural waste that now occurs through evaporation, transpiration from plants of little or no value, and escape of surface water; but there is probably no practicable way of effecting this increase in total recovery without reducing the flow of the creek.

The total appropriations for irrigation from Lodgepole Creek amount to nearly 400 second-feet,¹ but the natural flow of the creek at any point is only a fraction of the amount appropriated. If the water of the creek is diverted at some point, other water will seep into the channel below the point of diversion, and not far below there is likely to be a considerable stream. Obviously, the channel of the creek where it is not normally dry has somewhat the function of a well. It extends below the ground-water level, and hence when its water is removed the supply is replenished from the underground reservoir. Thus the underground reservoir is already utilized, water being artificially drawn from it in the irrigation season through the ditches that lead from the creek. Pumping from wells would, in a sense, be an extension of the same process and would result in a still more effective use of the underground reservoir. Pumping from wells extending to the subjacent formation—the second or lower water horizons—would interfere less with the stream flow than pumping from shallow wells. By bringing to the surface water that had been confined by an impervious bed pumping from the deeper wells might even raise the water table and add to the stream flow.

In order to make even an approximate estimate of the quantity of water that could be recovered by pumping from wells, it would be necessary to have much more information than is at present available in regard to the average annual discharge of Lodgepole Creek, the loss by evaporation and transpiration, and other factors that are involved.

According to official records of the States of Wyoming and Nebraska, the area irrigated from Lodgepole Creek and its tributaries amounted in 1912 to about 23,500 acres.² A large part of the water

¹ Price, D. D., Nebraska State Board of Irrigation, Highways, and Drainage Tenth Bienn. Rept., p. 49, 1914. Jabelmann, Louise, Tabulation of adjusted rights in water division No. 1, pp. 121-123, Wyoming State Board of Control, 1912.

² Price, D. D., op. cit., p. 117. Jabelmann, Louise, op. cit., pp. 121-123.

applied in irrigation percolates back to the underground reservoir. If it is assumed that the net annual withdrawal of water for irrigation is 2 acre-feet per acre, and that 23,500 acres are irrigated, the total net withdrawal is 47,000 acre-feet a year, or less than 3 per cent of the precipitation on the drainage basin of Lodgepole Creek. If the deposits underlying Lodgepole Valley are assumed to have an available porosity of 20 per cent, this amount of water is stored in $1\frac{1}{2}$ feet of depth of the underground reservoir. If, on these assumptions, the irrigated area were increased 20 per cent by pumping from wells, the average lowering of the water table caused by pumping during an irrigation season would not exceed 0.3 foot, and there would probably be almost complete recovery through recharge during the rest of the year. If the irrigated area were doubled the lowering during an irrigation season would be within $1\frac{1}{2}$ feet, but it would probably be enough to interfere seriously with the stream flow. Moreover, there would probably not be complete recovery by recharge in unfavorable seasons and thus the lowering might progress from year to year. Of course, the more widely distributed are the areas irrigated with well water the greater will be the salvage and the less will be the average effect on the water table and on the stream flow.

QUALITY.

The table on pages 54-55 gives two analyses of water from Lodgepole Creek and 20 analyses of waters from wells in or near Lodgepole Valley. Twelve of these analyses were made under contract for the United States Geological Survey by S. C. Dinsmore in connection with the present investigation, nine were made by the Union Pacific Railroad Co. under the direction of N. F. Harriman, chief chemist, and one was made by the Kennicott Water Softener Co. Three of the analyses (Nos. 13, 14, and 22) are of water from shallow wells that end in the alluvial gravel; seven (Nos. 8, 9, 11, 12, 17, 18, and 21) of water from the Brule clay, underlying the alluvium, with more or less admixture of water from the alluvium; two (Nos. 15 and 16) apparently from the Ogalalla formation underlying the alluvium; one (No. 4) from the upland gravel deposits above the sandstone of the Arikaree formation; two (Nos. 7 and 10) from the sandstone of the Arikaree formation; and one (No. 2) probably from the Fox Hills formation.

The water of the streams that flow from the granitic area of the mountain province (No. 1) is low in total solids and is of the calcium carbonate type. In passing over the outcropping sedimentary rocks the mineral content of the stream water appears, however, to be more than doubled in the course of a few miles, a large part of the addition evidently being from the gypsum beds of the Chugwater formation that outcrop at the edge of the mountains (see analysis No. 3).

None of the ground waters that were analyzed differ to any great extent from the sample of stream water; and in view of their rather wide geographic distribution and the diversity of their geologic sources they are remarkably similar to each other in total dissolved solids and in the proportions of the various constituents. None of them are highly mineralized, but all contain a moderate amount of dissolved mineral matter, the principal constituents being calcium and the bicarbonate radicle. They range in total solids from 212 to 501 parts per million, in calcium from 34 to 75 parts, in magnesium from 9.4 to 18 parts, in sodium and potassium from 1.9 to 65 parts, in bicarbonate from 130 to 371 parts, in sulphate from 12 to 70 parts, and in chloride from 2.6 to 20 parts.

The water from the Brule clay contains on an average somewhat more mineral matter than the rest. The largest content of total solids was found in sample No. 21, which was taken from the Brule clay at a depth of 90 feet, the water from higher horizons being shut out. Some of the upland wells that end in the Brule clay are said to yield poor water, but no analyses are available to substantiate this report. The analyses given in the table also seem to indicate a slight general increase in mineralization in the downstream direction.

So far as is shown by the analyses, the waters of this region are all satisfactory for irrigation, the content of sodium in none of them being high. They are also in general good for domestic uses except that their rather high content of calcium and magnesium renders them moderately hard. They deposit considerable soft scale in steam boilers but are used without serious trouble in the locomotives on the Union Pacific and other railroads and for steam making wherever required. At some points along the railroad, however, the water is treated at softening plants before it is used in locomotives.

Mineral analyses and classification of waters in or near Lodgepole Valley, Wyo.-Nebr.

[Parts per million except as otherwise designated.]

No.	Owner or name.	Location.	Well or creek.	Depth of well.	Diameter of well.	Water-bearing formation.	Depth to water level.	Date sample was collected.	Analyst.
1	North Fork of Lodgepole Creek.	Near east margin of sec. 27, T. 16 N., R. 70 W.; at granite contact west of Islay, Wyo.	Creek.	Ft.	Ft. in.			Sept. 16, 1915	S. C. Dinsmore.
2	Islay flowing wells...	Near railroad station, Islay, Wyo.	North flowing well.	150-300		Fox Hills formation (?)		do.	Do.
3	Lodgepole Creek at Hesham ranch.	Near east margin sec. 23, T. 16 N., R. 66 W.	Creek.					Sept. 17, 1915	Do.
4	W. H. Thompson...	S. 1/4 sec. 19, T. 16 N., R. 68 W.	Drilled well.	260		Gravelly phase of Arkarees formation.	251 0	Sept. 15, 1915	Do.
5	Union Pacific R. R.	Hillsdale, Wyo.	do.	66	13 0			Jan. 25, 1911	Union Pacific R. R.
6	do.	Durham, Wyo.	do.	405	8			do.	Do.
7	E. H. Hesthman	Burns, Wyo.	do.	134		Arkarees sandstone.		Sept. 20, 1915	S. C. Dinsmore.
8	Union Pacific R. R.	Egbert, Wyo.	Dug well.	35	16 0	Brule clay underlying dry alluvial gravel.	28 0	Jan. 25, 1911	Union Pacific R. R.
9	Bert Tucker.	Egbert, Wyo., NW 1/4 sec. 18, T. 14 N., R. 61 W.	do.	26		Alluvial gravel and underlying Brule clay.	23 0	Sept. 20, 1915	S. C. Dinsmore.
10	Arnold Wilkowske.	Egbert, Wyo., SE 1/4 sec. 6, T. 14 N., R. 61 W.	Drilled well.	179		Arkarees sandstone.	140 0	do.	Do.
11	Waterworks well.	Pinebluff, Wyo.	do.	76	14 6	Brule clay below alluvial gravel.	16 0	Sept. 13, 1915	Do.
12	Union Pacific R. R.	do.	Dug well.	25	16	do.	12 0	Sept. 15, 1913	Union Pacific R. R.
13	do.	Bushnell, Nebr.	do.	37	15 0	Alluvial gravel.		Jan. 25, 1911	Do.
14	Waterworks well.	Kimball, Nebr., in valley north of city.	Drilled well.	30	5 2	do.		Sept. 22, 1915	S. C. Dinsmore.
15	do.	Potter, Nebr., near east edge of village.	do.	72	12 6	Ogallala formation underlying alluvial gravel (?)	33 6	Sept. 23, 1915	Do.
16	Union Pacific R. R.	Potter, Nebr.	Dug well.	37	15 0	Ogallala formation (?)	(e)	Jan. 25, 1911	Union Pacific R. R.
17	Waterworks well.	Sidney, Nebr., on Main Street, near north edge of city.	do.	37±	15 0	Alluvial gravel and Brule clay.	26 0	Sept. 5, 1915	S. C. Dinsmore.
18	Union Pacific R. R.; Well No. 1.	Sidney, Nebr.	do.	33	12 0	Brule clay below alluvial gravel.		Sept. 17, 1910	Union Pacific R. R.
19	Well No. 2.	do.	do.	40	16 0	do.		do.	Do.
20	Union Pacific R. R.	do.	do.					Dec. 9, 1902	Kennelott Water Softener Co.
21	do.	Lodgepole, Nebr.	Dug and drilled well.	56			8 0	Nov. 11, 1913	Union Pacific R. R.
22	J. C. Johnson	do.	Drilled well.	90		Brule clay below alluvial gravel.		Sept. 8, 1915	S. C. Dinsmore.
22	Union Pacific R. R.	Chappell, Nebr.	do.	32	16 0	Alluvial gravel.	22 0	Sept. 17, 1910	Union Pacific R. R.

a Few feet above bottom.

No.	Determined quantities.										Computed quantities. ^a					Classification.						
	Silica (SiO ₂).	Iron (Fe).	Oxides of iron and aluminum (Fe ₂ O ₃ +Al ₂ O ₃).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO ₃).	Bicarbonate radicle (HCO ₃).	Sulphate radicle (SO ₄).	Chloride (Cl).	Nitrate radicle (NO ₃).	Total dissolved solids.	Total hardness as CaCO ₃ .	Scale-forming ingredients.	Foaming ingredients.	Probability of corrosion.	Alkali coefficient.	Mineral content.	(Chemical character.	Quality for domestic use.	Quality for boilers.	Quality for irrigation.
1	17	Tr.	.....	26	6.3	11.0	0.0	100	6.5	2.0	0.0	113	90	100	3	(?)	Inches 680	Low	Ca-CO ₂	Good	Good	Good
2	33	Tr.	.....	54	12	10.4	8.4	202	12	7.5	2.0	231	180	210	25	(?)	280	Moderate	do	do	Poor	Do.
3	37	Tr.	.....	55	10	17.5	9.6	161	38	5.0	0	247	230	220	20	(?)	320	do	do	do	do	Do.
4	49	Tr.	.....	54	11	14.5	0	183	21	8.0	8.0	245	180	230	12	(?)	250	do	do	do	do	Do.
5	20	Tr.	.....	43	12	10	0	146	34	16	0.25	212	160	170	27	(?)	130	do	do	do	Fair	Do.
6	60	Tr.	.....	46	9.4	11	0	173	15	13	0.5	244	150	210	30	(?)	150	do	do	do	Poor	Do.
7	55	Tr.	.....	43	13	14.3	0	185	14	6.5	18	255	180	230	12	(?)	310	do	do	do	Good	Do.
8	39	Tr.	.....	34	10	15	0	130	36	12	0.05	213	130	190	40	(?)	140	do	do	do	Fair	Do.
9	30	Tr.	.....	71	11	11.9	0	212	22	4.0	30	264	220	260	5	(?)	510	do	do	do	Poor	Do.
10	57	Tr.	.....	41	12	14	0	216	14	5.0	5.0	266	150	240	65	(?)	40	do	do	do	do	Do.
11	12	Tr.	.....	69	16	16	15	272	30	11	6.2	372	240	240	70	(?)	70	do	do	do	Fair	Do.
12	41	Tr.	.....	51	12	23	0	225	20	16	12	280	190	210	81	(?)	47	do	do	do	do	Do.
13	43	Tr.	.....	68	16	16.4	0	281	33	12	5.0	342	240	280	60	(?)	71	do	do	do	do	Do.
14	51	Tr.	.....	51	13	13	0	193	13	7.0	16	246	180	220	37	(?)	120	do	do	do	do	Do.
15	52	Tr.	.....	51	12	13	0	181	35	20	Tr.	262	190	220	35	(?)	270	do	do	do	do	Do.
16	36	Tr.	.....	41	11	11	0	200	13	5.0	8.0	253	190	200	45	(?)	100	do	do	do	Fair	Do.
17	53	Tr.	.....	52	14	16	0	215	38	10	25	280	190	220	60	(?)	75	do	do	do	Poor	Do.
18	45	Tr.	.....	52	13	21	0	219	70	18	.....	343	220	250	70	(?)	140	do	do	do	do	Do.
19	19	Tr.	.....	62	17	25	0	264	37	2.6	12	344	190	230	100	(?)	90	do	do	Fair	do	Do.
20	49	Tr.	.....	56	12	37	0	371	67	5.5	25	501	260	300	180	(?)	33	do	do	do	do	Do.
21	54	Tr.	.....	75	13	13	0	371	67	9.3	25	501	260	300	180	(?)	19	do	do	do	do	Do.
22	56	Tr.	.....	65	12	12	0	300	41	.....	.....	353	210	250	110	(?)	31	do	do	do	do	Do.

^a The following formulas, adapted by Dole (U. S. Geol. Survey Water-Supply Paper 375, pp. 160, 163-164) from those of Stabler (Water-Supply Paper 274) have been used for computing the total hardness (H) as CaCO₃, the probable scale-forming ingredients (S), the probable foaming ingredients (F), and the tendency to cause corrosion (C):
 $H = 2.5 \text{ Ca} + 4.1 \text{ Mg}$
 $S = \text{SiO}_2 + 2.95 \text{ Ca} + 1.66 \text{ Mg}$
 $F = 2.7 (\text{Na} + \text{K})$
 $C = -0.0828 \text{ Mg} - 0.0336 \text{ CO}_3 - 0.0165 \text{ HCO}_3$ is positive no corrosion will occur because of the mineral constituents of the water (N. C.). If 0.0828 Mg - 0.0336 CO₃ - 0.0165 HCO₃ is negative but 0.0828 Mg + 0.0503 CO₂ - 0.0165 HCO₃ is positive corrosion may or may not occur (?).
 In these formulas SiO₂, Ca, Mg, Na+K, CO₂ and HCO₃ represent, respectively, the amounts in parts per million of silica, calcium, magnesium, sodium, potassium, carbonate, and bicarbonate. The comparative value of the waters for irrigation has been estimated by applying the formulas developed by Stabler for calculating the "alkali coefficient," which is defined by him as the depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

The alkali coefficients (k) are computed by means of the following formulas:
 $k = \frac{2.040}{\text{Cl}}$ if Na - 0.65 Cl is zero or negative.
 $k = \frac{2.040}{\text{Na} + 2.6 \text{ Cl}}$ if Na - 0.65 Cl is positive but not more than 0.48 SO₄.
 $k = \frac{6.620}{\text{Na} - 0.32 \text{ Cl} - 0.43 \text{ SO}_4}$ if Na - 0.65 Cl - 0.48 SO₄ is positive.

^b Calculated.
^c Reported by Union Pacific Railroad Co. in hypothetical combinations in grains per gallon; recalculated into ionic form in parts per million, and carbonate expressed as bicarbonate.

DATA CONCERNING WELLS.

LARAMIE COUNTY, WYO.

The few wells in the valley above Egbert are used only for domestic supply and for watering stock and their capacity has not been thoroughly tested. Some of the wells between Egbert and Pole Creek ranch are drilled and most of them end in sand of the Arikaree formation. The alluvial gravels would no doubt yield large supplies in much of this part of the valley, but they are not widely distributed and are generally not deep. The drilled wells in the vicinity of Islay are described on pages 63, 64.

The railroad well at Egbert is 35 or 40 feet deep, 16 feet in diameter, and is walled with stone laid in cement. It was sunk through dry gravel into "hardpan" which contains water-bearing crevices. The men in charge report that the well contains 7 feet of water, and that pumping at the rate of 150 gallons a minute lowers the water level very little.

The well that supplies the Pinebluff waterworks is 76 feet deep; the upper 16 feet is a dug pit, the rest a drilled hole with 12-inch perforated casing. The water level is about 16 feet below the surface. When the well was sunk there was, according to Mr. M. Ekstrom, the driller, only 4 inches of water-bearing gravel, below which the well penetrated Brule clay, the crevices of which furnish nearly all of the water. The pump is set 15 feet below the water level, and pumping 220 gallons a minute is reported by Mr. Ekstrom to cause a drawdown of 2.5 feet, indicating a yield of 90 gallons a minute for each foot of drawdown.

The railroad well at Pinebluff is about 25 feet deep and 14½ feet in diameter and, like the Egbert well, is walled with stone laid in cement. It was sunk through 8 feet of silty loam and a few feet of dry gravel, and ended in vesicular Brule clay, in which a satisfactory supply was obtained. The water level is about 12 feet below the surface, and, according to authentic information, is lowered 3 or 4 inches when the well is pumped at 150 gallons a minute and about 6 inches when it is pumped at 225 gallons a minute, indicating a capacity of about 450 gallons a minute for 1 foot of drawdown. When the well was being sunk it is reported to have been pumped simultaneously by a 5-inch and a 4-inch centrifugal pump.

The well of Mr. Ekstrom, in the SW. ¼ sec. 10, T. 14 N., R. 60 W., about 250 feet from the creek, is 13 feet deep, 20 feet in diameter, and is walled with concrete. It extends through gravel to the "hardpan." The water level is only 3 feet below the surface and the water is derived from the gravel. The well failed to supply a 5-inch centrifugal pump which has a capacity of 735 gallons a minute but is supposed to yield about half this amount, or approximately 35 gallons for each foot of drawdown.

A well dug by Mr. Ekstrom, 8 miles southwest of Pinebluff, only about 30 feet from the banks of Muddy Creek, to a depth of 20 feet, ends in "hardpan" but fails to supply a 4-inch centrifugal pump. Some of the wells between Pinebluff and Egbert yield supplies inadequate for domestic use or for stock.

KIMBALL COUNTY, NEBR.

The railroad well at Bushnell is 37 feet deep and 15 feet in diameter and is walled with stone laid in cement. It extends through gravel to the "hardpan." Pumping at the rate of 170 gallons a minute empties the well.

The railroad well at Kimball, which is on the second terrace, 60 feet above the level of the creek, is 93 feet deep and its water level is about 60 feet below the surface. A 16-foot hole was sunk to a depth of about 85 feet and was walled with stone laid in cement. This hole extended through dry gravel to a depth of 30 or 40 feet and thence through "hardpan" to the bottom, where a thin layer of water-bearing sand and gravel was found. The yield was unsatisfactory, and a hole was drilled in the bottom of this well to another water-bearing bed, which is said to consist of gravel. This increased the supply so much that pumping at the rate of 170 gallons a minute is reported not to lower the water level greatly, but pumping at 285 gallons a minute is reported to empty the well. The information regarding both the Bushnell and the Kimball railroad wells was furnished chiefly by Mr. J. R. McCart, in charge of the Union Pacific water supply between Durham, Wyo., and Julesburg, Colo.

The well that supplies the waterworks at Kimball is in the valley about one-fourth mile from the creek and about 15 feet above the creek level. It consists of a 5-foot hole that extends to a depth of 15 feet, where water was encountered, and a 2-foot hole with perforated casing that extends down about 16 feet from the bottom of the 5-foot hole. The entire well is in gravel. According to T. C. Thiele, who has charge of the pumping plant, the usual pumpage, as indicated by a meter, is 230 gallons a minute, and pumping at about this rate for 8 hours has produced a drawdown of only $1\frac{1}{2}$ feet, indicating a capacity of about 150 gallons a minute for each foot of drawdown.

The well of Mr. Gus. Forsling is in the NE. $\frac{1}{4}$ sec. 34, T. 15 N., R. 57 W., near the upper end of the Kimball reservoir. A 6-foot hole, walled with cement, goes to a depth of 18 or 20 feet, and a 14-inch suction pipe with a screen 4 or 5 feet long extends below the bottom of the 6-foot hole to about 31 feet below the surface. The entire well is in gravel. When tested on September 21, 1915, the water level was 15.45 feet below the bench mark, or about 15 feet below the surface, and pumping for one hour at an average rate of

445 gallons a minute, according to two measurements made with a current meter, lowered the water level to 18.05 feet below the bench mark, or a distance of 2.60 feet. This test therefore indicated that the well has a capacity of about 170 gallons a minute for each foot of drawdown. Mr. Forsling reported that in a 12-hour run the water level was lowered about 4 feet. Data in regard to the pumping plant are given on pages 65-67.

Wells sunk by Anton Linder and J. F. Bogle for irrigation of land not far east of Bushnell are supposed to yield satisfactory supplies but had not been severely tested at the time the valley was examined.

CHEYENNE COUNTY, NEBR.

The well that supplies the waterworks at Potter is 72 feet deep and is lined with 12-inch casing to a depth of 48 feet and 6-inch casing to the bottom, the casing being perforated with numerous holes one-fourth inch in diameter. The section, as reported, is as follows: Water at 35 feet; water-bearing sand and gravel to 48 feet; "rock" to 50 feet; soft white clay to 63 feet; water-bearing sand and gravel to 72 feet, well ending in gravel. The depth to the water level September 23, 1915, was 34.65 feet below the platform, or 33.5 feet below the surface. The pumpage averages about 10,000 gallons a day. According to A. D. Irey, who is in charge of both village and railroad pumping plants, the well was tested at 120 gallons a minute, and this rate of pumping lowered the water level 3 feet, indicating a capacity of 40 gallons a minute for each foot of drawdown.

The railroad well at Potter is 37 feet deep, 15 feet in diameter, and is walled with stone laid in cement. It is reported to extend through gravel, "hardpan," and "rock." The water level is only a few feet above the bottom of the well. According to Mr. Irey, the well is pumped at about 125 gallons a minute, and this rate of pumping for 6 hours emptied the well in the fall of 1914 but not in the summer of 1915.

The well that supplies the waterworks at Sidney yields more than any other well that was examined. It is about 37 feet deep, 15 feet in diameter, and is walled with stone. It extends through gravel to a depth of about 28 feet, below which it is in "hardpan." At the time the well was dug the lowest $1\frac{1}{2}$ feet of gravel was saturated with water; on September 5, 1915, the water level was 26 feet below the surface. This well supplies about 28,000,000 gallons a year, or an average of about 80,000 gallons a day. In a test made September 5, 1915, it was pumped for one hour at 710 gallons a minute, as measured by the installed meter, and the water level was lowered only 0.31 foot. Pumping for three hours at about 650 gallons a minute is reported to produce a drawdown of about 8 inches. It is also reported that before any "hardpan" had been excavated the

well was pumped at 1,100 gallons a minute without emptying it, all of the water presumably coming from the 18-inch layer of saturated gravel.

The Union Pacific Railroad Co. has two wells in Sidney that are somewhat similar to the city well. The new well is 40 feet deep, 16 feet in diameter, walled with stone laid in cement. It was sunk through dry gravel to the depth of 24 feet and through "hardpan" from this depth to the bottom, the first water being struck in crevices in the "hardpan" at a depth of about 30 feet. Mr. J. R. McCart reports that while the well was being sunk it was pumped 550 gallons a minute without exhausting the supply and that the well is usually pumped at about 350 gallons a minute. The old well is not so deep as the new one and yields less water.

Other wells in Sidney that yield considerable water are the Chicago, Burlington & Quincy Railroad well, the schoolhouse well, and the well at the J. A. Reisdorff ice factory. The railroad well is a large dug hole reported to have only about 4 feet of water but to yield freely. The schoolhouse well has 7-inch casing and is said to be about 45 feet deep. It was pumped on September 3, 1915, at 35 gallons a minute, at which rate it is frequently pumped for 10 or 12 hours. The ice-factory well is a dug hole about 50 feet deep and is said to be a strong well, although it is pumped at a rate of only 10 or 12 gallons a minute.

The well that supplies the waterworks at Lodgepole is 100 feet deep, the upper 17 feet being a dug hole and the rest a drilled hole 14 inches in diameter. The first water was struck in gravel at the depth of 17 feet, and "hardpan" was reached at 17½ feet. Most of the supply is reported to have been found between the depths of 50 and 75 feet. The well is usually pumped at about 110 gallons a minute. This rate of pumping is reported to produce a drawdown, in some seasons of 5 or 6 feet, but at the time the well was examined, September 9, 1915, the drawdown was only about 1 foot.

The railroad well at Lodgepole is 56 feet deep. It consists of a dug hole about 30 feet deep and three 3-inch drilled holes extending 26 feet downward from the bottom of the dug hole. As reported by Mr. J. J. Finnegan, who is in charge of the railroad water supply at this place and at Chappell, the well passed through water-bearing gravel between the depths of 7 and 11 feet and through hard clay from 11 feet to the bottom. The water level is about 8 feet below the surface. Pumping at the rate of 115 gallons a minute is reported by Mr. Finnegan to lower the water level about 2 feet in the first hour of pumping, after which there is no noticeable lowering even though the pump is run all day. In tests made September 9 and 10, 1915, the drawdown was 1.35 feet after 20 minutes of pumping and 2.1 feet after 1 hour and 15 minutes, 2 hours, and 3 hours of

pumping. These tests therefore indicated a capacity of about 55 gallons a minute for each foot of drawdown.

A few wells have been sunk in Cheyenne County to obtain water for irrigation, but none of them were being pumped in September, 1915. The dug well of Mr. Nels Olson, 2 miles west of Sidney, is 16 feet deep, and in September, 1915, the water level was 9.8 feet below the surface. This well is equipped with a pump rated at 750 gallons a minute, but no test of the yield was made. A shallow well, 8 feet in diameter, dug near the creek, on the Benjamin Glenn estate, in the SW. $\frac{1}{4}$ sec. 33, T. 14 N., R. 49 W., was formerly provided with a rather large pumping plant to be used for irrigation, but it is now abandoned. The Campbell wells, on land now belonging to Mr. George Graves, in the NE. $\frac{1}{4}$ sec. 35, T. 14 N., R. 47 W., were sunk to obtain a supply for irrigation but were not in use in 1915. There are five wells at intervals of 25 feet and a little less than 50 feet from the creek. As reported by Mr. J. C. Johnson, the driller, they were at first carried to depths of only 16 to 18 feet and were finished in gravel with 12-inch perforated casings. The depth to water level was about 7 feet. They yielded considerable water but did not adequately supply the 6-inch centrifugal pump with which they were simultaneously pumped. Two of the wells were then extended as 8-inch uncased holes, through the "hardpan" to a total depth of 80 feet. Additional water struck in the "hardpan" rose to a level 2 or 3 feet above the original water level. These two wells, according to Mr. Johnson, supplied the pump. The discharge of the pumping plant is reported to have been 1,380 gallons a minute, but this report was not verified.

DEUEL COUNTY, NEBR.

The well that supplies the waterworks at Chappell is 4 feet in diameter and 34 feet deep and extends through gravel to the top of the clay. The water level is about 28 feet below the surface. According to Mr. R. H. Libby, who is in charge of the plant, the well is usually pumped at a rate of about 85 gallons a minute but has been tested at 200 gallons a minute. It supplies 5,000 to 30,000 gallons a day.

The railroad well at Chappell is 16 feet in diameter and 32 feet deep, and ends in gravel. The water level is reported to be about 22 feet below the surface. When measured by Mr. Finnegan, in 1916, pumping at the rate of 200 gallons a minute for several hours lowered the water level only $1\frac{1}{2}$ feet.

The principal attempt in this part of the valley to recover ground water for irrigation was made by Mr. Skip McNew, who sank five 14-inch wells near the creek on sec. 12, T. 12 N., R. 45 W., and installed a 6-inch centrifugal pump. In 1915 the plant had been abandoned, but from such meager information as could be obtained

it appears that the wells supplied the pump, which probably had a capacity of about 900 gallons a minute.

Near the Colorado State line Lodgepole Valley opens into the valley of the South Platte, which is wider, has a somewhat deeper deposit of alluvial gravel, and no doubt has a larger supply of ground water. At Julesburg, Colo., just below the mouth of Lodgepole Valley, both city and railroad supplies are derived from the alluvial gravel, which is here about 40 feet thick.

The Julesburg waterworks are supplied by two wells, 14 feet apart, both of which, according to Mr. C. H. Lent, superintendent of the city waterworks, are 40 feet deep and have 14-inch sheet-iron casings with perforations $1\frac{1}{4}$ inches long and one-fourth inch wide. The water level is about 12 feet below the surface. It is reported that either of these wells will supply 750 gallons a minute with the suction pipe extending 15 feet below the water level. In a brief test made September 8, 1915, the two wells together supplied 750 gallons a minute, or somewhat more, with an average drawdown of 3.33 feet, indicating a capacity for each well, when both are being pumped, of about 110 gallons a minute for each foot of drawdown.

The railroad supply at Julesburg is obtained from a well 16 feet deep and 12 feet in diameter, ending in gravel. The water level is 5 feet below the surface. In September, 1915, the well supplied 300 gallons a minute, but in dry seasons it has been emptied by pumping 200 gallons a minute. This information was furnished by Mr. McCart.

WATER IN TERTIARY FORMATIONS.

The Tertiary formations, named in their order from the top downward, are the Ogallala formation, the Arikaree formation, the Brule clay, and the Chadron sandstone. They are described on pages 39-42, and their water-bearing capacity where they lie below the alluvium is discussed on page 47.

The Ogallala formation, which underlies large parts of the Great Plains, generally yields abundant supplies of good water from the irregular gravelly beds which it contains. This formation supplies most of the wells in the region adjacent to Lodgepole Valley east of Pinebluff, but in some places the base of the formation is so high above the valley that the water drains out of it and wells must be sunk into the underlying Brule clay.

The Arikaree formation consists largely of sandstone, the lower part of which is saturated with water that it yields rather freely to wells. Most of the drilled wells ending in this formation are cased to prevent caving, but some of the dug wells are left uncased. The sand causes some trouble by running into wells that are finished with

open ends or with large perforations in the casings and by clogging screens of finer mesh. So far as possible screens of fine mesh should be avoided, and the difficulty with sand should be overcome by thorough cleaning out and hard pumping at the time the wells are finished. If necessary gravel should be inserted to hold back the sand. As shown by analyses 7 and 10 (pp. 54-55) the water from the Arikaree formation contains only a moderate amount of mineral matter, which consists chiefly of silica, calcium, and bicarbonate, the two last named rendering it somewhat hard. It is of good quality for irrigation. The sandstone of this formation is reached by wells on the upland and in the valley from the vicinity of the Pole Creek ranch to a point a little beyond Egbert. No traces of the formation were found farther east in or near Lodgepole Valley.

The wells on the uplands for some miles east of the Islay escarpment are supplied by water from gravelly beds that overlie the typical sandstone of the Arikaree formation. The water level here is rather deep, but the supplies are abundant and the water is good. A sample of the water was taken from the drilled well of Mr. W. H. Thompson in the S. $\frac{1}{4}$ sec. 19, T. 16 N., R. 68 W. (No. 4 in table on p. 54). This well is on the upland, 250 feet above the valley, in the region where the gravelly deposits extend down to the valley. The well is 260 feet deep and the depth to water level is said to be 251 feet. The owner reported that it passes through "clay and gravel" and ends in water-bearing "sand and gravel." The lowest 20 feet of casing is perforated to admit the water. The well yields freely and the water is good. East of the vicinity of the Pole Creek ranch the base of the gravelly deposits is generally above the water level and the wells penetrate the underlying sandstone.

The Brule clay is in general too dense to be a good water bearer and some wells drilled into it have been failures. In most places, however, it yields supplies that are adequate for domestic uses and for watering stock, and in parts of the valley it yields very freely. The water generally comes from the joints into which the formation readily breaks, but a few wells end in sand that appears to be interbedded with the clay. Most of the wells between Egbert and Pinebluff end in Brule clay and some of them are unsatisfactory. Many of the upland wells near Sidney and in other localities east of Pinebluff have also been drilled into the Brule clay and most of these yield some water. Although this formation yields water freely at many places in the valley, it becomes tighter near the margins of the valley, where wells have been drilled into it a few hundred feet without finding much water. The water from the Brule clay apparently contains somewhat more mineral matter than that from the overlying formations. It would deposit large amounts of scale in

boilers but, so far as the analyses show, it is not generally too highly mineralized for domestic use or for irrigation. (See especially analysis No. 21, pp. 54-55.)

So few wells have been sunk to the base of the Brule clay that there is little information regarding the Chadron sandstone, which, near the mountains, crops out below this clay. In the few deep wells that have been drilled either this sandstone was absent or it did not supply much water. The flowing well at the city pumping plant in Julesburg, Colo., passed through "yellow shale" between the depths of 40 and 200 feet, and "blue shale" between the depths of 200 and 400 feet, where the drilling was stopped. A 4-inch bed of sand between the two shale beds yielded a natural flow amounting to a fraction of 1 gallon a minute. If the "yellow shale" is the Brule clay, this thin bed of sand is at the horizon of the Chadron sandstone. Some of the other wells that reached sand after passing through the Brule clay may end in Chadron sandstone.

WATER IN CRETACEOUS AND OLDER FORMATIONS.

The formations in the general section shown on page 39 doubtless extend eastward beneath Lodgepole Valley, probably with some changes in character and thickness. The two notable facts regarding this section are that the Dakota sandstone, which in the vicinity of the Laramie Mountains is included in the Cloverly formation, is a widespread and very important artesian horizon and that the Pierre shale is a very thick and impervious formation which will produce little water and that of poor quality. Throughout most of its great thickness the Pierre shale consists of a dark plastic homogeneous shale. Above it and below the Tertiary system in this region there are alternating sandy and shaly beds (Fox Hills and other formations) which will yield some water, but which, so far as is now known, are not strong water bearers. Below the Pierre shale—between this shale and the Dakota sandstone—lie the Niobrara limestone and the Benton shale, which also contain water-bearing members. Below the Dakota sandstone there are still other water-bearing formations, but they lie too far below the surface in this region to be considered as sources of water supply.

There are two flowing wells at Islay station and a 6-inch drilled well on slightly lower ground in sec. 27, in the same township, in which the water level in September, 1915, stood 3 feet below the surface, or 5.4 feet below the top of the casing. Definite information regarding the depths and sections of these wells could not be obtained, but according to N. H. Darton¹ they are from 150 to 300 feet deep

¹ Darton, N. H., Blackwelder, Elliot, and Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Laramie-Sherman folio (No. 173), p. 17, 1910.

and apparently derive their water from the Fox Hills sandstone. On September 16, 1915, the south well at Islay flowed about 2 gallons a minute and the north well about 10 gallons a minute. The water is of good quality, as is shown by analysis No. 2 (pp. 54-55). A well at Cheyenne, which is reported to have been 1,145 feet deep, passed through much sand and obtained a small flow but was not considered successful.¹ A well on the farm of Mr. Frank Hand, about 6 miles south of Sidney, is said to have been sunk to a depth of about 1,000 feet and to have obtained only a small yield. If the well reached this depth it probably entered the Pierre shale. At Sterling, Colo., in the valley of the South Platte, a well is reported to have been sunk to a depth of 600 feet, chiefly through blue shale. Artesian water that flowed 2 or 3 gallons a minute is reported to have been struck in a thin bed of sand at a depth of about 400 feet.

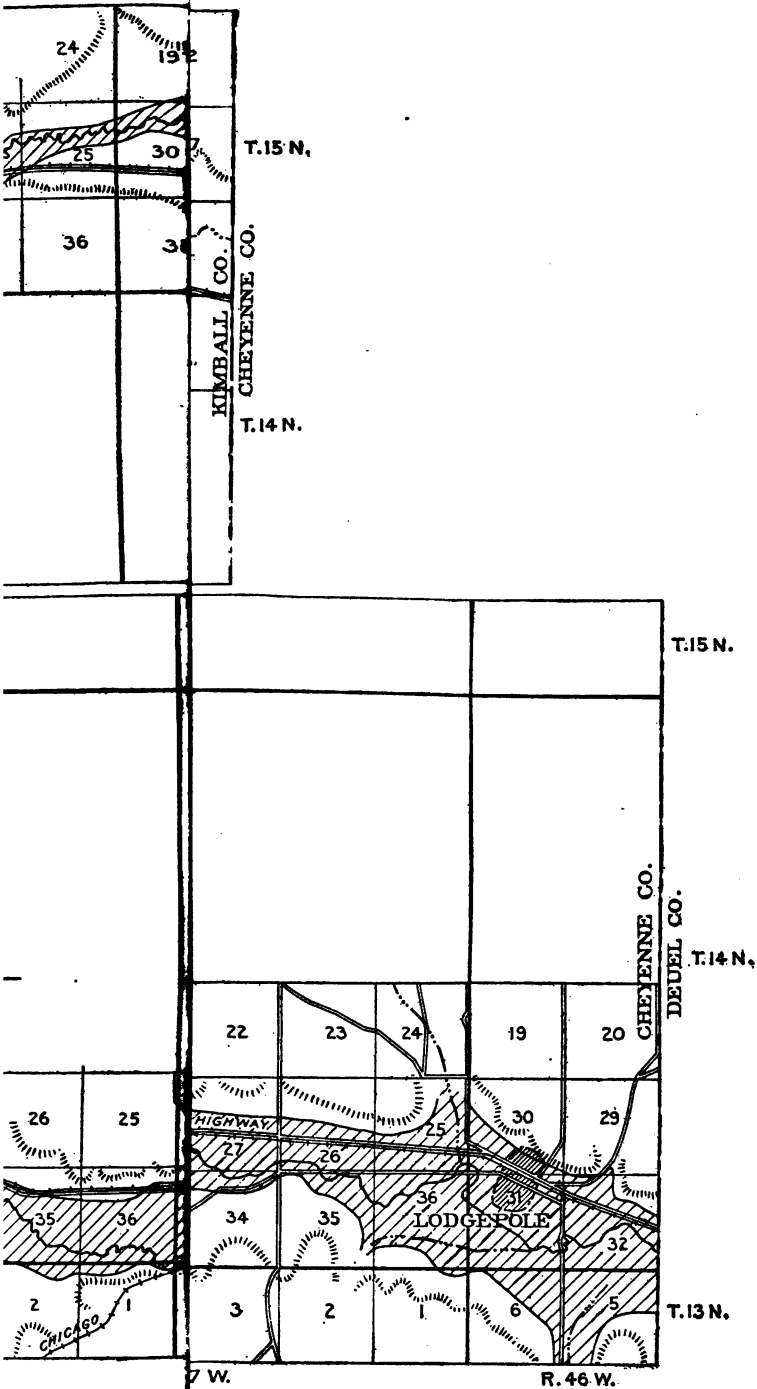
Too few wells have been sunk in this region to test adequately the water-bearing beds above the Pierre shale, and none of them were deep enough to reach the beds below the Pierre shale. There is some prospect of obtaining flowing wells by deep drilling in Lodgepole Valley from formations above or below the Pierre shale, but the prospect of obtaining adequate supplies at a cost low enough for irrigation by deep drilling must be regarded as poor. The formations above the Pierre shale could be tested by wells not more than 1,000 feet deep, but unless the formations are much thinner toward the east than where they outcrop, wells several thousand feet deep would be required to reach the Dakota sandstone.

IRRIGATION WITH GROUND WATER.

The problem of irrigation with well water in Lodgepole Valley relates chiefly to the cost and to the quantity of water available. Several wells have been sunk in the valley to obtain water for irrigation, but in 1915 only a few of these wells were used and some of them had been permanently abandoned. The supply has generally been large enough but the difficulty has been rather in the work and cost of pumping and applying the water.

The cost of pumping varies within wide limits. Success or failure depends largely on the care and the ability with which the plant is installed and operated. With good management, pumping for the irrigation of staple crops should at present be economically practicable in those parts of Lodgepole Valley where satisfactory wells can be obtained, where there is good soil to which to apply the water, and where the water table is within 25 feet of the surface. (See Pls.

¹ Darton, N. H., Preliminary report on the geology and underground-water resources of the central Great Plains; U. S. Geol. Survey Prof. Paper 22, p. 206, 1906.



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IV, V, and VI.) Under favorable conditions pumping can probably be made profitable even where the depth to the water table is somewhat more than 25 feet. One of the chief causes of failure in a semi-arid region, such as Lodgepole Valley, is that in the years of sufficient precipitation the pumping plants are neglected and are consequently out of repair when they are again needed.

The most practical type of pumping plant for Lodgepole Valley consists of one or more drilled wells, a centrifugal pump with a capacity of not less than about 1 second-foot and not more than several second-feet, and an internal-combustion engine adapted to the use of low-grade, inexpensive distillate, the water to be used in the vicinity of the pumping plant.

Where the water is obtained from gravel the wells can be dug by hand, but in general adequate supplies can be obtained at less cost by digging only to the water level and below this level sinking wells 8 to 14 inches in diameter and using casings that are abundantly perforated. In some localities it will be advisable to sink the wells into the "hardpan." Where sufficient water is not obtained from one well, several wells can be sunk, 50 to 100 feet apart, and connected with the same pump.

Where the water table is not more than 25 feet below the surface, horizontal centrifugal pumps are commonly used, these pumps being installed just above the water level and connected with the engine by a belt that makes an angle of not more than 45° with the horizontal. Vertical centrifugal pumps are generally submerged. They are adapted to use in wells in which the water level lies rather deep or fluctuates greatly.

A large central power plant with electric-transmission lines extending to the individual pumping units, such as have been installed near Garden City, Kans., and at Portales, N. Mex., would probably have some advantage in economy and convenience over small engines installed at the pumps, but the installation of such a plant is not recommended at present for Lodgepole Valley, especially because pumping on a large scale would probably interfere with existing rights to the stream water.

The following data in regard to the pumping plant of Mr. Gus. Forsling in the NE. $\frac{1}{4}$ sec. 34, T. 15 N., R. 57 W. (see p. 57), were obtained in part from the owner and in part by a test made on September 21, 1915. In its general features this plant is more or less typical of the pumping plants that are best adapted to the conditions in this valley.

Data in regard to the pumping plant of Mr. Gus. Forsling, near Bushnell, Nebr.

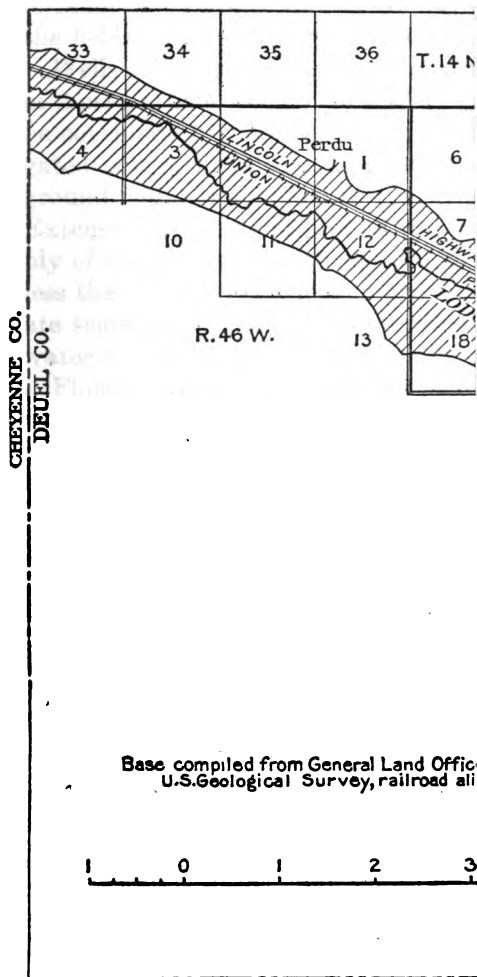
Well, 31 feet deep, 14-inch casing below cement-lined pump pit, ending in gravel.
 Pump, 5-inch vertical centrifugal.
 Power, 18-horsepower gasoline engine.
 Cost of well, pump, and engine, \$867.
 Estimated total cost of plant, \$1,000.
 Normal water level, below surface, 15 feet.
 Normal water level, below discharge, 33 feet.
 Drawdown, about 4 feet.
 Total lift, about 37 feet.
 Rated capacity of pump, about 1.5 second-foot.
 Yield when tested, September 21, 1915, 1 second-foot.
 Gasoline used, 1½ gallons per hour.
 Cost of gasoline, 12 cents per gallon.
 Useful work accomplished (lifting 1 second-foot of water 37 feet), 4.2 horsepower.
 Energy expended, counting 1 pint of gasoline per horsepower-hour, 13.3 horsepower.
 Efficiency, 31.6 per cent.
 Gasoline required to pump 1 acre-foot of water. (1 second-foot during 12 hours), 20 gallons.
 Cost of gasoline to pump 1 acre-foot, \$2.40.

In the preceding table the estimate of yield of water is based on a test of about 1 hour, made September 21, 1915, but the estimate of the consumption of gasoline is based on a run of 19 hours. If in the longer run the water table stood higher or the yield of the pump was more nearly its rated capacity the conclusions as to efficiency and cost per acre-foot may be somewhat vitiated. The price of gasoline has advanced since the test was made, but distillates costing less than 12 cents could be used. Where fuel is consumed in relatively small quantities kerosene, which is cheaper than gasoline, is frequently used. There are, of course, many other expenses besides the cost of the fuel, such as lubricants, repairs and renewals, labor, and fixed charges, such as taxes and interest on investment.

According to Mr. Forsling the plant will irrigate 1 acre in 2 hours, and one irrigation will serve to raise a crop of fully 1 ton of alfalfa. According to the above figures, such an irrigation would be only 2 inches deep, and even if the pump worked at its rated capacity it would be only 3 inches deep. This involves a much higher duty of water than is usually attained, even in regions having as much rainfall as Lodgepole Valley. On soil that is not too porous it should be possible on the average to raise a ton of alfalfa with one-half or two-thirds of an acre-foot of irrigation water, although frequently the amount used is greater.¹ If the Forsling plant were operated 80 days during the irrigation season for an average of 12 hours a day it would yield 80 acre-feet of water, which, with a duty of two-thirds acre-foot per ton of alfalfa, would produce 120 tons of this hay.

¹ Bark, D. H., Experiments on the economical use of irrigation water in Idaho: U. S. Dept. Agr. Bull. 539, 1916.

U. S. GEOLOGICAL SURVEY



MAP OF LODGEPOLE VALLEY IN DE

Area indicated by shading is underlain by water-lain material. Boundaries of valley are indefinite but are outside of an surface.

The data given above indicate a cost for fuel of \$1.60 for each ton of alfalfa raised. Assuming that interest and taxes amount to 9 per cent and that renewals, repairs, and other expenses amount to 15 per cent of the original investment of \$1,000, these items would add \$2 per ton, making a total cost of \$3.60 per ton, exclusive of the cost of labor in pumping and, of course, exclusive of the cost of planting the fields, applying the water, and harvesting the crop.

Wells yielding enough water for practical irrigation can be obtained in most parts of Lodgepole Valley, and the total irrigated area could be considerably increased by pumping. However, the area now irrigated is very large in comparison to the size of the stream, because ground water is supplied to the stream during the irrigation season. Extensive pumping of ground water would reduce the available supply of stream water, although the decrease in stream water would be less than the increase in pumped well water. Pumping on a moderate scale will probably not appreciably reduce the supply of stream water and is doubtless practicable in Lodgepole Valley.

Flowing wells could probably be obtained by deep drilling in some parts of the valley, but the prospects are not encouraging for obtaining supplies from deep wells in quantities or at costs practicable for irrigation.

COST OF PUMPING FOR IRRIGATION IN WESTERN NEBRASKA.

By H. C. DIESEN.¹

During the growing season of 1914 the rainfall was 2.49 inches below normal in the northwestern part of Nebraska, 1.40 inches below in the western part, and 1.60 inches below in the southwestern part, and the general average rainfall for the western half of the State was 2.08 inches below the normal.

During this and the preceding dry seasons considerable interest was manifested in pumping, and numerous pumping plants were installed and operated throughout the State. In 1915 the precipitation was above the average, and none of the pumping plants were operated, but in the season of 1916 a drouth existed during the month of July and many of the plants were again operated.

The Division of Irrigation Investigations, Office of Public Roads and Rural Engineering, United States Department of Agriculture, obtained records of some of the pumping plants operated during the seasons of 1914 and 1916 but has not yet compiled the data for 1916.

The records for 1914 have been arranged in the order of the cost of pumping an acre-foot per foot lift, which ranged from 4.35 cents

¹ Division of Irrigation Investigations, Office of Public Roads and Rural Engineering, U. S. Department of Agriculture.

to 13 cents. The operations during that season showed some very good runs, ranging from 81 to 600 hours for the season, at a total cost of operation, exclusive of labor, ranging from \$36.19 to \$185.76 for the season's pumping. The cost of pumping an acre-foot ranged from \$1.502 to \$3.636, but as the lift ranged from 28 to 45 feet a true comparison must be based on the cost of pumping an acre-foot per foot lift.

It is noteworthy that the maximum cost per acre-foot delivered was at a plant having one of the two lowest lifts. This fact can be due only to low efficiency of the plant. Though plant No. 1 delivered water at only 4.35 cents per acre-foot per foot lift, plants Nos. 2, 3, and 4, operated at a higher cost, furnished water on the land at a lower cost not only per acre irrigated but also per acre-inch applied. This difference is explained by the fact that the lift on No. 1 was greater and that the actual quantity of water applied to the land under plant No. 1 was but a trifle less than that from No. 2 and greater than that from Nos. 3 and 4. Plant No. 1 was also handicapped by not having a well of sufficient capacity to supply the pump; and though the engine is supposedly self-governing, it was not operated to its full capacity but was speeded down, and the plant was run below its rated capacity to avoid drawing down the well and sucking air, and thus breaking the suction of the pump.

Results of operating certain pumping plants in Nebraska in 1914.

Plant.				Pumping.		Cost.			Area to which water was applied once.
No.	Engine.	Pump. ^a	Lift.	Time.	Quantity.	Total for season.	Per acre-foot.	Per acre-foot per foot lift.	
	Horsepower.		Feet.	H. m.	Acres-feet.		Cents.		Acres.
1.....	25	5 T	45	436 35	40.11	\$78.52	\$1.958	4.35	100
2.....	15	6 H	34	487 00	47.07	70.69	1.502	4.42	104.6
3.....	25	6 V	40	116 55	19.68	37.27	1.894	4.74	68
4.....	15	5 V	28	190 00	27.23	43.65	1.603	5.73	63
5.....	20	6 V	31	128 00	18.88	36.19	1.917	6.18	41.5
6.....	22	6 H	43	96 00	13.12	36.40	2.774	6.45	35
7.....	15	5 H	32	600 25	80.06	185.76	2.320	7.25	220
8.....	30	6 V	44	81 00	15.79	54.11	3.426	7.79	60
9.....	15	6 V	35	355 30	26.96	32.40	3.056	8.73	120
10.....	20	5 H	33	176 00	14.67	43.48	2.962	8.98	48.5
11.....	18	5 H	28	151 00	14.23	38.40	2.699	9.63	28
12.....	15	6 H	28	90 00	11.70	42.54	3.636	13.00	20

^a Centrifugal pumps. Figure indicates number or size. H=horizontal, V=vertical, T=turbine.

The last column shows the number of acres to which water was applied once; for instance, plant No. 7 irrigated 110 acres twice, which is equivalent to irrigating 220 acres once.

The following table shows the number of times the crop was irrigated and the cost of applying the water to that crop:

Number and cost of irrigations at certain pumping plants in Nebraska in 1914.

Plant No.	Crop irrigated.	Area irrigated, in acres.	Number of irrigations.	Water applied.		Cost.	
				Total, in acre-feet.	Acre-inches per acre.	Per acre.	Per acre-inch
1.....	Corn.....	40.0	2	30.29	9.09	\$1.482	\$0.163
2.....	Beets.....	37.3	2	32.86	10.56	1.222	.127
3.....	Corn.....	25	2	14.62	7.02	1.104	.158
4.....	do.....	20	2	15.05	9.03	1.206	.133
5.....	do.....	10	2	9.38	11.25	1.754	.160
6.....	do.....	35	1	13.12	4.50	1.040	.231
7.....	do.....	110	2	80.06	16.01	1.689	.106
8.....	do.....	3	3	1.76	7.04	2.008	.290
9.....	do.....	60	2	26.96	5.39	1.373	.255
10.....	do.....	48	1	13.54	3.39	.835	.247
11.....	do.....	12	2	10.66	10.66	2.397	.225
12.....	do.....	20	1	11.70	7.02	2.127	.303

HYDRAULIC CONVERSION TABLES AND CONVENIENT EQUIVALENTS.

DEFINITION OF TERMS.

The volume of water flowing in a stream—the “run-off” or “discharge”—is expressed in various terms, each of which has become associated with a certain class of work. These terms may be divided into two groups—(1) those that represent a rate of flow, as second-feet, gallons per minute, miner’s inches, and discharge in second-feet per square mile, and (2) those that represent the actual quantity of water, as run-off in depth of inches, acre-feet, and millions of cubic feet. The principal terms may be defined as follows:

“Second-foot” is an abbreviation for “cubic feet per second.” A second-foot is the rate of discharge of water flowing in a channel of rectangular cross section 1 foot wide and 1 foot deep at an average velocity of 1 foot per second. It is generally used as a fundamental unit from which others are computed by the use of the factors.

“Second-feet per square mile” is the average number of cubic feet of water flowing per second from each square mile of area drained on the assumption that the run-off is distributed uniformly both as regards time and area.

“Run-off, depth in inches,” is the depth to which the drainage area would be covered if all the water flowing from it in a given period were conserved and uniformly distributed on the surface. It is used for comparing run-off with rainfall, which is usually expressed in depth of inches.

An “acre-foot” is equivalent to 43,560 cubic feet and is the quantity required to cover an acre to the depth of 1 foot. The term is commonly used in connection with storage for irrigation.

“Millions of cubic feet” is used to express quantities of water stored in reservoirs, most frequently in connection with studies of flood control.

“Gallons per minute” and “millions of gallons” are generally used in connection with pumping and city water supply.

The “miner’s inch” is the rate of discharge of water that passes through an orifice 1 inch square under a head which varies locally. It is commonly used by miners and irrigators throughout the West and is defined by statute in each State in which it is used.

EXPLANATION OF TABLES.

The conversion from one unit to another is a simple arithmetical process. The following specially prepared tables afford a ready means of conversion between the terms in common use in hydraulic computations. The results are taken out separately for units, hundreds, etc., and then combined to get the desired result. As the conversion of second-feet per square mile to run-off in depth in inches, and second-feet to acre-feet are very frequent operations in the preparation of stream-flow records, the tables for these operations have been expanded to give directly without computation or interpolation the desired results for months of 28, 29, 30, and 31 days.

Attention is called to the fact that although the tables will give results to more than three significant figures, it is seldom that the base data or the requirements for which the records are collected will justify the use of more than three significant figures.

CONVERSION TABLES.

Discharge in second-feet per square mile into run-off in depth in inches.

[1 second-foot for 1 day = 86,400 cubic feet = $\frac{86,400 \times 12}{27,878,400} = 0.03719$ inch deep on 1 square mile.]

Discharge (second-feet per square mile).	Run-off (depth in inches).				
	1 day.	28 days.	29 days.	30 days.	31 days.
1	0.03719	1.041	1.079	1.116	1.153
2	.07438	2.083	2.157	2.231	2.306
3	.11157	3.124	3.236	3.347	3.459
4	.14876	4.165	4.314	4.463	4.612
5	.18595	5.207	5.393	5.578	5.764
6	.22314	6.248	6.471	6.694	6.917
7	.26033	7.289	7.550	7.810	8.070
8	.29752	8.331	8.628	8.926	9.223
9	.33471	9.372	9.707	10.041	10.376

NOTE.—For part of month multiply run-off for 1 day by number of days.

Discharge in second-feet into run-off in acre-feet.

[1 second-foot for 1 day = 86,400 cubic feet = $\frac{86,400}{43,560} = 1.983471$ acre-feet.]

Discharge (second- feet).	Run-off (acre-feet).				
	1 day.	28 days.	29 days.	30 days.	31 days.
1	1.983	55.54	57.52	59.50	61.49
2	3.967	111.1	115.0	119.0	123.0
3	5.950	166.6	172.6	178.5	184.5
4	7.934	222.1	230.1	238.0	246.0
5	9.917	277.7	287.6	297.5	307.4
6	11.90	333.2	345.1	357.0	368.9
7	13.88	388.8	402.6	416.5	430.4
8	15.87	444.3	460.2	476.0	491.9
9	17.85	499.8	517.7	535.5	553.4

NOTE.—For part of month multiply run-off for 1 day by number of days.

Discharge in second-feet into run-off in millions of cubic feet.

[1 second-foot for 1 day=86,400 cubic feet=0.0864 million cubic feet.]

Discharge (second- feet).	Run-off (millions of cubic feet).				
	1 day.	28 days.	29 days.	30 days.	31 days.
1.....	0.0864	2.419	2.506	2.592	2.678
2.....	.1728	4.838	5.012	5.184	5.356
3.....	.2592	7.257	7.518	7.776	8.034
4.....	.3456	9.676	10.02	10.37	10.71
5.....	.4320	12.10	12.53	12.96	13.39
6.....	.5184	14.51	15.04	15.55	16.07
7.....	.6048	16.93	17.54	18.14	18.75
8.....	.6912	19.35	20.05	20.74	21.42
9.....	.7776	21.77	22.55	23.33	24.10

NOTE.—For part of month multiply run-off for 1 day by the number of days.

Discharge in second-feet into run-off in millions of gallons.[1 second-foot for 1 day=86,400 cubic feet= $\frac{86,400 \times 1,728}{231}$ —646,317 gallons=0.646317 million gallons.]

Discharge (second- feet).	Run-off (millions of gallons).				
	1 day.	28 days.	29 days.	30 days.	31 days.
1.....	0.6463	18.10	18.74	19.39	20.04
2.....	1.293	36.20	37.48	38.78	40.08
3.....	1.939	54.30	56.22	58.17	60.12
4.....	2.585	72.40	74.96	77.56	80.16
5.....	3.232	90.50	93.70	96.95	100.2
6.....	3.878	108.6	112.4	116.3	120.2
7.....	4.524	126.7	131.2	135.7	140.3
8.....	5.170	144.8	149.9	155.1	160.3
9.....	5.817	162.9	168.7	174.5	180.4

NOTE.—For part of month multiply run-off for 1 day by the number of days.

Run-off in millions of gallons per day into discharge in second-feet.[1 million gallons per 24 hours= $\frac{231,000,000}{1,728 \times 86,400}$ cubic feet per second, or 1.547 second-feet.]

Tens.	Units.									
	0	1	2	3	4	5	6	7	8	9
0.....		1.55	3.09	4.64	6.19	7.74	9.28	10.83	12.38	13.93
1.....	15.47	17.02	18.57	20.11	21.66	23.21	24.76	26.30	27.85	29.40
2.....	30.94	32.49	34.04	35.59	37.13	38.68	40.23	41.78	43.32	44.87
3.....	46.42	47.96	49.51	51.06	52.61	54.15	55.70	57.25	58.79	60.34
4.....	61.89	63.44	64.98	66.53	68.08	69.63	71.17	72.72	74.27	75.81
5.....	77.36	78.91	80.46	82.00	83.55	85.10	86.64	88.19	89.74	91.29
6.....	92.83	94.38	95.93	97.48	99.02	100.57	102.12	103.66	105.21	106.76
7.....	108.31	109.85	111.40	112.95	114.49	116.04	117.59	119.14	120.68	122.23
8.....	123.78	125.33	126.87	128.42	129.97	131.51	133.06	134.61	136.16	137.70
9.....	139.25	140.80	142.34	143.89	145.44	146.99	148.53	150.08	151.63	153.18

Run-off in millions of gallons into run-off in acre-feet.

[1 million United States liquid gallons or 231 million cubic inches = 133,680.555 cubic feet, or $\frac{133,680}{43,560} = 3.0690$ acre-feet.]

Tens.	Units.									
	0	1	2	3	4	5	6	7	8	9
0.....		3.07	6.14	9.21	12.28	15.34	18.41	21.48	24.55	27.62
1.....	30.69	33.76	36.83	39.90	42.96	46.03	49.10	52.17	55.24	58.31
2.....	61.38	64.45	67.52	70.58	73.65	76.72	79.79	82.86	85.93	89.00
3.....	92.07	95.14	98.20	101.27	104.34	107.41	110.48	113.55	116.62	119.69
4.....	122.76	125.82	128.89	131.96	135.03	138.10	141.17	144.24	147.31	150.38
5.....	153.44	156.51	159.58	162.65	165.72	168.79	171.86	174.93	178.00	181.06
6.....	184.13	187.20	190.27	193.34	196.41	199.48	202.55	205.62	208.68	211.75
7.....	214.82	217.89	220.96	224.03	227.10	230.17	233.24	236.30	239.37	242.44
8.....	245.51	248.58	251.65	254.72	257.79	260.86	263.92	266.99	270.06	273.13
9.....	276.20	279.27	282.34	285.41	288.48	291.54	294.61	297.68	300.75	303.82

Discharge in gallons per minute into discharge in second-feet.

[1 gallon per minute = $\frac{231}{60}$ cubic inches per second = $\frac{231}{60 \times 1,728} = 0.0022278$ second-foot.]

Tens.	Units.									
	0	1	2	3	4	5	6	7	8	9
0.....		0.0022	0.0045	0.0067	0.0089	0.0111	0.0134	0.0156	0.0178	0.0201
1.....	0.0223	.0245	.0267	.0290	.0312	.0334	.0356	.0379	.0401	.0423
2.....	.0446	.0468	.0490	.0512	.0535	.0557	.0579	.0602	.0624	.0646
3.....	.0668	.0691	.0713	.0735	.0757	.0780	.0802	.0824	.0847	.0869
4.....	.0891	.0913	.0936	.0958	.0980	.1003	.1025	.1047	.1069	.1092
5.....	.1114	.1136	.1158	.1181	.1203	.1225	.1248	.1270	.1292	.1314
6.....	.1337	.1359	.1381	.1404	.1426	.1448	.1470	.1493	.1515	.1537
7.....	.1559	.1582	.1604	.1626	.1649	.1671	.1693	.1715	.1738	.1760
8.....	.1782	.1805	.1827	.1849	.1871	.1894	.1916	.1938	.1960	.1983
9.....	.2005	.2027	.2050	.2072	.2094	.2116	.2139	.2161	.2183	.2206

Discharge in second-feet into run-off in acre-feet for a year of 365 days.

[1 second-foot = 86,400 cubic feet in 1 day = $\frac{86,400 \times 365}{43,560} = 723.966942$ acre-feet in 1 year.]

Tens.	Units.									
	0	1	2	3	4	5	6	7	8	9
0.....		724	1,448	2,172	2,896	3,620	4,344	5,068	5,792	6,516
1.....	7,240	7,964	8,688	9,412	10,136	10,860	11,583	12,307	13,031	13,755
2.....	14,479	15,203	15,927	16,651	17,375	18,099	18,823	19,547	20,271	20,995
3.....	21,719	22,443	23,167	23,891	24,615	25,339	26,063	26,787	27,511	28,235
4.....	28,959	29,683	30,407	31,131	31,855	32,579	33,303	34,026	34,750	35,474
5.....	36,198	36,922	37,646	38,370	39,094	39,818	40,542	41,266	41,990	42,714
6.....	43,438	44,162	44,886	45,610	46,334	47,058	47,782	48,506	49,230	49,954
7.....	50,678	51,402	52,126	52,850	53,574	54,298	55,021	55,745	56,469	57,193
8.....	57,917	58,641	59,365	60,089	60,813	61,537	62,261	62,985	63,709	64,433
9.....	65,157	65,881	66,605	67,329	68,053	68,777	69,501	70,225	70,949	71,673

Velocity in feet per second into velocity in miles per hour.

[1 foot per second = 0.681818 mile per hour, or two-thirds mile per hour, very nearly; 1 mile per hour = 1.4666 feet per second. In computing the table the values 0.68182 and 1.4667 were used.]

Feet per second (units).	Miles per hour for tenths of foot per second.									
	0	1	2	3	4	5	6	7	8	9
0.....	0.000	0.068	0.136	0.205	0.273	0.341	0.409	0.477	0.545	0.614
1.....	.682	.750	.818	.886	.955	1.02	1.09	1.16	1.23	1.30
2.....	1.36	1.43	1.50	1.57	1.64	1.70	1.77	1.84	1.91	1.98
3.....	2.05	2.11	2.18	2.25	2.32	2.39	2.45	2.52	2.59	2.66
4.....	2.73	2.80	2.86	2.93	3.00	3.07	3.14	3.20	3.27	3.34
5.....	3.41	3.48	3.55	3.61	3.68	3.75	3.82	3.89	3.95	4.02
6.....	4.09	4.16	4.23	4.30	4.36	4.43	4.50	4.57	4.64	4.70
7.....	4.77	4.84	4.91	4.98	5.05	5.11	5.18	5.25	5.32	5.39
8.....	5.45	5.52	5.59	5.66	5.73	5.80	5.86	5.93	6.00	6.07
9.....	6.14	6.20	6.27	6.34	6.41	6.48	6.55	6.61	6.68	6.75

Discharge in second-feet per square mile into run-off in depth in inches per year of 365 days.

No.	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.136	0.272	0.407	0.543	0.679	0.814	0.950	1.086	1.222
0.1	1.357	1.493	1.629	1.765	1.900	2.036	2.172	2.308	2.443	2.579
0.2	2.715	2.851	2.986	3.122	3.258	3.394	3.529	3.665	3.801	3.937
0.3	4.072	4.208	4.344	4.480	4.615	4.751	4.887	5.023	5.158	5.294
0.4	5.430	5.565	5.701	5.837	5.973	6.108	6.244	6.380	6.516	6.651
0.5	6.787	6.923	7.059	7.194	7.330	7.466	7.602	7.737	7.873	8.009
0.6	8.145	8.280	8.416	8.552	8.688	8.823	8.959	9.095	9.231	9.366
0.7	9.502	9.638	9.774	9.909	10.045	10.181	10.317	10.452	10.588	10.724
0.8	10.860	10.995	11.131	11.267	11.402	11.538	11.674	11.810	11.945	12.081
0.9	12.217	12.353	12.488	12.624	12.760	12.896	13.031	13.167	13.303	13.439
1.0	13.574	13.710	13.846	13.982	14.117	14.253	14.389	14.525	14.660	14.796
1.1	14.932	15.068	15.203	15.339	15.475	15.611	15.746	15.882	16.018	16.153
1.2	16.289	16.425	16.561	16.696	16.832	16.968	17.104	17.239	17.375	17.511
1.3	17.647	17.782	17.918	18.054	18.190	18.325	18.461	18.597	18.733	18.868
1.4	19.004	19.140	19.276	19.411	19.547	19.683	19.819	19.954	20.090	20.226
1.5	20.362	20.497	20.633	20.769	20.904	21.040	21.176	21.312	21.447	21.583
1.6	21.719	21.855	21.990	22.126	22.262	22.398	22.533	22.669	22.805	22.941
1.7	23.076	23.212	23.348	23.484	23.619	23.755	23.891	24.027	24.162	24.298
1.8	24.434	24.570	24.705	24.841	24.977	25.113	25.248	25.384	25.520	25.656
1.9	25.791	25.927	26.063	26.198	26.334	26.470	26.606	26.741	26.877	27.013
2.0	27.149	27.284	27.420	27.556	27.692	27.827	27.963	28.099	28.235	28.370
2.1	28.506	28.642	28.778	28.913	29.049	29.185	29.321	29.456	29.592	29.728
2.2	29.864	29.999	30.135	30.271	30.407	30.542	30.678	30.814	30.950	31.085
2.3	31.221	31.357	31.492	31.628	31.764	31.900	32.035	32.171	32.307	32.443
2.4	32.578	32.714	32.850	32.986	33.121	33.257	33.393	33.529	33.664	33.800
2.5	33.936	34.072	34.207	34.343	34.479	34.615	34.750	34.886	35.022	35.158
2.6	35.293	35.429	35.565	35.701	35.836	35.972	36.108	36.244	36.379	36.515
2.7	36.651	36.786	36.922	37.058	37.194	37.329	37.465	37.601	37.737	37.872
2.8	38.008	38.144	38.280	38.415	38.551	38.687	38.823	38.958	39.094	39.230
2.9	39.366	39.501	39.637	39.773	39.909	40.044	40.180	40.316	40.452	40.587
3.0	40.723	40.859	40.995	41.130	41.266	41.402	41.538	41.673	41.809	41.945

For year of 366 days multiply by 1.00274.

Discharge in second-feet per square mile into run-off in depth in inches per month of 25 days.

No.	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.010	0.021	0.031	0.042	0.052	0.062	0.073	0.083	0.094
.1	.104	.115	.125	.135	.146	.156	.167	.177	.187	.198
.2	.208	.219	.229	.240	.250	.260	.271	.281	.292	.302
.3	.312	.323	.333	.344	.354	.364	.375	.385	.396	.406
.4	.417	.427	.437	.448	.458	.469	.479	.489	.500	.510
.5	.521	.531	.541	.552	.562	.573	.583	.594	.604	.614
.6	.625	.635	.646	.656	.666	.677	.687	.698	.708	.719
.7	.729	.739	.750	.760	.771	.781	.791	.802	.812	.823
.8	.833	.843	.854	.864	.875	.885	.896	.906	.916	.927
.9	.937	.948	.958	.968	.979	.989	1.000	1.010	1.020	1.031
1.0	1.041	1.052	1.062	1.073	1.083	1.093	1.104	1.114	1.125	1.135
1.1	1.145	1.156	1.166	1.177	1.187	1.198	1.208	1.218	1.229	1.239
1.2	1.250	1.260	1.270	1.281	1.291	1.302	1.312	1.322	1.333	1.343
1.3	1.354	1.364	1.375	1.385	1.395	1.406	1.416	1.427	1.437	1.447
1.4	1.458	1.468	1.479	1.489	1.500	1.510	1.520	1.531	1.541	1.552
1.5	1.562	1.572	1.583	1.593	1.604	1.614	1.624	1.635	1.645	1.656
1.6	1.666	1.677	1.687	1.697	1.708	1.718	1.729	1.739	1.749	1.760
1.7	1.770	1.781	1.791	1.801	1.812	1.822	1.833	1.843	1.854	1.864
1.8	1.874	1.885	1.895	1.906	1.916	1.926	1.937	1.947	1.958	1.968
1.9	1.979	1.989	1.999	2.010	2.020	2.031	2.041	2.051	2.062	2.072
2.0	2.083	2.093	2.103	2.114	2.124	2.135	2.145	2.156	2.166	2.176
2.1	2.187	2.197	2.208	2.218	2.228	2.239	2.249	2.260	2.270	2.280
2.2	2.291	2.301	2.312	2.322	2.333	2.343	2.353	2.364	2.374	2.385
2.3	2.395	2.405	2.416	2.426	2.437	2.447	2.458	2.468	2.478	2.489
2.4	2.499	2.510	2.520	2.530	2.541	2.551	2.562	2.572	2.582	2.593
2.5	2.603	2.614	2.624	2.635	2.645	2.655	2.666	2.676	2.687	2.697
2.6	2.707	2.718	2.728	2.739	2.749	2.759	2.770	2.780	2.791	2.801
2.7	2.812	2.822	2.832	2.843	2.853	2.864	2.874	2.884	2.895	2.905
2.8	2.916	2.926	2.937	2.947	2.957	2.968	2.978	2.989	2.999	3.009
2.9	3.020	3.030	3.041	3.051	3.061	3.072	3.082	3.093	3.103	3.114
3.0	3.124	3.134	3.145	3.155	3.166	3.176	3.186	3.197	3.207	3.218
3.1	3.228	3.239	3.249	3.259	3.270	3.280	3.291	3.301	3.311	3.322
3.2	3.332	3.343	3.353	3.363	3.374	3.384	3.395	3.405	3.416	3.426
3.3	3.436	3.447	3.457	3.468	3.478	3.488	3.499	3.509	3.520	3.530
3.4	3.540	3.551	3.561	3.572	3.582	3.593	3.603	3.613	3.624	3.634
3.5	3.645	3.655	3.665	3.676	3.686	3.697	3.707	3.718	3.728	3.738
3.6	3.749	3.759	3.770	3.780	3.790	3.801	3.811	3.822	3.832	3.842
3.7	3.853	3.863	3.874	3.884	3.895	3.905	3.915	3.926	3.936	3.947
3.8	3.957	3.967	3.978	3.988	3.999	4.009	4.019	4.030	4.040	4.051
3.9	4.061	4.072	4.082	4.092	4.103	4.113	4.124	4.134	4.144	4.155
4.0	4.165	4.176	4.186	4.197	4.207	4.217	4.228	4.238	4.249	4.259
4.1	4.269	4.280	4.290	4.301	4.311	4.321	4.332	4.342	4.353	4.363
4.2	4.374	4.384	4.394	4.405	4.415	4.426	4.436	4.446	4.457	4.467
4.3	4.478	4.488	4.499	4.509	4.519	4.530	4.540	4.551	4.561	4.571
4.4	4.582	4.592	4.603	4.613	4.623	4.634	4.644	4.655	4.665	4.676
4.5	4.686	4.696	4.707	4.717	4.728	4.738	4.748	4.759	4.769	4.780
4.6	4.790	4.800	4.811	4.821	4.832	4.842	4.853	4.863	4.873	4.884
4.7	4.894	4.905	4.915	4.925	4.936	4.946	4.957	4.967	4.978	4.988
4.8	4.998	5.009	5.019	5.030	5.040	5.050	5.061	5.071	5.082	5.092
4.9	5.102	5.113	5.123	5.134	5.144	5.155	5.165	5.175	5.186	5.196

Discharge in second-feet per square mile into run-off in depth in inches per month of 28 days—Continued.

No.	0	1	2	3	4	5	6	7	8	9
5.0	5.207	5.217	5.227	5.238	5.248	5.259	5.269	5.279	5.290	5.300
5.1	5.311	5.321	5.332	5.342	5.352	5.363	5.373	5.384	5.394	5.404
5.2	5.415	5.425	5.436	5.446	5.457	5.467	5.477	5.488	5.498	5.509
5.3	5.519	5.529	5.540	5.550	5.561	5.571	5.581	5.592	5.602	5.613
5.4	5.623	5.634	5.644	5.654	5.665	5.675	5.686	5.696	5.706	5.717
5.5	5.727	5.738	5.748	5.758	5.769	5.779	5.790	5.800	5.811	5.821
5.6	5.831	5.842	5.852	5.863	5.873	5.883	5.894	5.904	5.915	5.925
5.7	5.936	5.946	5.956	5.967	5.977	5.988	5.998	6.008	6.019	6.029
5.8	6.040	6.050	6.060	6.071	6.081	6.092	6.102	6.113	6.123	6.133
5.9	6.144	6.154	6.165	6.175	6.185	6.196	6.206	6.217	6.227	6.238
6.0	6.248	6.258	6.269	6.279	6.290	6.300	6.310	6.321	6.331	6.342
6.1	6.352	6.362	6.373	6.383	6.394	6.404	6.415	6.425	6.435	6.446
6.2	6.456	6.467	6.477	6.487	6.498	6.508	6.519	6.529	6.539	6.550
6.3	6.560	6.571	6.581	6.592	6.602	6.612	6.623	6.633	6.644	6.654
6.4	6.664	6.675	6.685	6.696	6.706	6.717	6.727	6.737	6.748	6.758
6.5	6.769	6.779	6.789	6.800	6.810	6.821	6.831	6.841	6.852	6.862
6.6	6.873	6.883	6.894	6.904	6.914	6.925	6.935	6.946	6.956	6.966
6.7	6.977	6.987	6.998	7.008	7.018	7.029	7.039	7.050	7.060	7.071
6.8	7.081	7.091	7.102	7.112	7.123	7.133	7.143	7.154	7.164	7.175
6.9	7.185	7.196	7.206	7.216	7.227	7.237	7.248	7.258	7.268	7.279
7.0	7.289	7.300	7.310	7.320	7.331	7.341	7.352	7.362	7.373	7.383
7.1	7.393	7.404	7.414	7.425	7.435	7.445	7.456	7.466	7.477	7.487
7.2	7.498	7.508	7.518	7.529	7.539	7.550	7.560	7.570	7.581	7.591
7.3	7.602	7.612	7.622	7.633	7.643	7.654	7.664	7.675	7.685	7.695
7.4	7.706	7.716	7.727	7.737	7.747	7.758	7.768	7.779	7.789	7.799
7.5	7.810	7.820	7.831	7.841	7.852	7.862	7.872	7.883	7.893	7.904
7.6	7.914	7.924	7.935	7.945	7.956	7.966	7.977	7.987	7.997	8.008
7.7	8.018	8.029	8.039	8.049	8.060	8.070	8.081	8.091	8.101	8.112
7.8	8.122	8.133	8.143	8.154	8.164	8.174	8.185	8.195	8.206	8.216
7.9	8.226	8.237	8.247	8.258	8.268	8.278	8.289	8.299	8.310	8.320
8.0	8.331	8.341	8.351	8.362	8.372	8.383	8.393	8.403	8.414	8.424
8.1	8.435	8.445	8.456	8.466	8.476	8.487	8.497	8.508	8.518	8.528
8.2	8.539	8.549	8.560	8.570	8.580	8.591	8.601	8.612	8.622	8.633
8.3	8.643	8.653	8.664	8.674	8.685	8.695	8.705	8.716	8.726	8.737
8.4	8.747	8.758	8.768	8.778	8.789	8.799	8.810	8.820	8.830	8.841
8.5	8.851	8.862	8.872	8.882	8.893	8.903	8.914	8.924	8.935	8.945
8.6	8.955	8.966	8.976	8.987	8.997	9.007	9.018	9.028	9.039	9.049
8.7	9.059	9.070	9.080	9.091	9.101	9.112	9.122	9.132	9.143	9.153
8.8	9.164	9.174	9.184	9.195	9.205	9.216	9.226	9.237	9.247	9.257
8.9	9.268	9.278	9.289	9.299	9.309	9.320	9.330	9.341	9.351	9.361
9.0	9.372	9.382	9.393	9.403	9.414	9.424	9.434	9.445	9.455	9.466
9.1	9.476	9.486	9.497	9.507	9.518	9.528	9.538	9.549	9.559	9.570
9.2	9.580	9.591	9.601	9.611	9.622	9.632	9.643	9.653	9.663	9.674
9.3	9.684	9.695	9.705	9.716	9.726	9.736	9.747	9.757	9.768	9.778
9.4	9.788	9.799	9.809	9.820	9.830	9.840	9.851	9.861	9.872	9.882
9.5	9.893	9.903	9.913	9.924	9.934	9.945	9.955	9.965	9.976	9.986
9.6	9.997	10.007	10.017	10.028	10.038	10.049	10.059	10.070	10.080	10.090
9.7	10.101	10.111	10.122	10.132	10.142	10.153	10.163	10.174	10.184	10.195
9.8	10.205	10.215	10.226	10.236	10.247	10.257	10.267	10.278	10.288	10.299
9.9	10.309	10.319	10.330	10.340	10.351	10.361	10.372	10.382	10.392	10.403

Discharge in second-feet per square mile into run-off in depth in inches per month of 29 days.

No.	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.011	0.022	0.032	0.043	0.054	0.065	0.075	0.086	0.097
.1	.108	.119	.129	.140	.151	.162	.173	.183	.194	.205
.2	.216	.226	.237	.248	.259	.270	.280	.291	.302	.313
.3	.324	.334	.345	.356	.367	.377	.388	.399	.410	.421
.4	.431	.442	.453	.464	.475	.485	.496	.507	.518	.528
.5	.539	.550	.561	.572	.582	.593	.604	.615	.626	.636
.6	.647	.658	.669	.679	.690	.701	.712	.723	.733	.744
.7	.755	.766	.777	.787	.798	.809	.820	.830	.841	.852
.8	.863	.874	.884	.895	.906	.917	.928	.938	.949	.960
.9	.971	.981	.992	1.003	1.014	1.025	1.035	1.046	1.057	1.068
1.0	1.079	1.089	1.100	1.111	1.122	1.132	1.143	1.154	1.165	1.176
1.1	1.186	1.197	1.208	1.219	1.230	1.240	1.251	1.262	1.273	1.283
1.2	1.294	1.305	1.316	1.327	1.337	1.348	1.359	1.370	1.380	1.391
1.3	1.402	1.413	1.424	1.434	1.445	1.456	1.467	1.478	1.488	1.499
1.4	1.510	1.521	1.531	1.542	1.553	1.564	1.575	1.585	1.596	1.607
1.5	1.618	1.629	1.639	1.650	1.661	1.672	1.682	1.693	1.704	1.715
1.6	1.726	1.736	1.747	1.758	1.769	1.780	1.790	1.801	1.812	1.823
1.7	1.833	1.844	1.855	1.866	1.877	1.887	1.898	1.909	1.920	1.931
1.8	1.941	1.952	1.963	1.974	1.984	1.995	2.006	2.017	2.028	2.038
1.9	2.049	2.060	2.071	2.082	2.092	2.103	2.114	2.125	2.135	2.146
2.0	2.157	2.168	2.179	2.189	2.200	2.211	2.222	2.233	2.243	2.254
2.1	2.265	2.276	2.286	2.297	2.308	2.319	2.330	2.340	2.351	2.362
2.2	2.373	2.384	2.394	2.405	2.416	2.427	2.437	2.448	2.459	2.470
2.3	2.481	2.491	2.502	2.513	2.524	2.534	2.545	2.556	2.567	2.578
2.4	2.588	2.599	2.610	2.621	2.632	2.642	2.653	2.664	2.675	2.685
2.5	2.696	2.707	2.718	2.729	2.739	2.750	2.761	2.772	2.783	2.793
2.6	2.804	2.815	2.826	2.836	2.847	2.858	2.869	2.880	2.890	2.901
2.7	2.912	2.923	2.934	2.944	2.955	2.966	2.977	2.987	2.998	3.009
2.8	3.020	3.031	3.041	3.052	3.063	3.074	3.085	3.095	3.106	3.117
2.9	3.128	3.138	3.149	3.160	3.171	3.182	3.192	3.203	3.214	3.225
3.0	3.236	3.246	3.257	3.268	3.279	3.289	3.300	3.311	3.322	3.333
3.1	3.343	3.354	3.365	3.376	3.387	3.397	3.408	3.419	3.430	3.440
3.2	3.451	3.462	3.473	3.484	3.494	3.505	3.516	3.527	3.538	3.548
3.3	3.559	3.570	3.581	3.591	3.602	3.613	3.624	3.635	3.645	3.656
3.4	3.667	3.678	3.689	3.699	3.710	3.721	3.732	3.742	3.753	3.764
3.5	3.775	3.786	3.796	3.807	3.818	3.829	3.839	3.850	3.861	3.872
3.6	3.883	3.893	3.904	3.915	3.926	3.937	3.947	3.958	3.969	3.980
3.7	3.990	4.001	4.012	4.023	4.034	4.044	4.055	4.066	4.077	4.088
3.8	4.098	4.109	4.120	4.131	4.141	4.152	4.163	4.174	4.185	4.195
3.9	4.206	4.217	4.228	4.239	4.249	4.260	4.271	4.282	4.292	4.303
4.0	4.314	4.325	4.336	4.346	4.357	4.368	4.379	4.390	4.400	4.411
4.1	4.422	4.433	4.443	4.454	4.465	4.476	4.487	4.497	4.508	4.519
4.2	4.530	4.541	4.551	4.562	4.573	4.584	4.594	4.605	4.616	4.627
4.3	4.638	4.648	4.659	4.670	4.681	4.692	4.702	4.713	4.724	4.735
4.4	4.745	4.756	4.767	4.778	4.789	4.799	4.810	4.821	4.832	4.843
4.5	4.853	4.864	4.875	4.886	4.896	4.907	4.918	4.929	4.940	4.950
4.6	4.961	4.972	4.983	4.994	5.004	5.015	5.026	5.037	5.047	5.058
4.7	5.069	5.080	5.091	5.101	5.112	5.123	5.134	5.144	5.155	5.166
4.8	5.177	5.188	5.198	5.209	5.220	5.231	5.242	5.252	5.263	5.274
4.9	5.285	5.295	5.306	5.317	5.328	5.339	5.349	5.360	5.371	5.382

Discharge in second-feet per square mile into run-off in depth in inches per month of 29 days—Continued.

No.	0	1	2	3	4	5	6	7	8	9
5.0	5.393	5.403	5.414	5.425	5.436	5.446	5.457	5.468	5.479	5.490
5.1	5.500	5.511	5.522	5.533	5.544	5.554	5.565	5.576	5.587	5.597
5.2	5.608	5.619	5.630	5.641	5.651	5.662	5.673	5.684	5.695	5.705
5.3	5.716	5.727	5.738	5.748	5.759	5.770	5.781	5.792	5.802	5.813
5.4	5.824	5.835	5.846	5.856	5.867	5.878	5.889	5.899	5.910	5.921
5.5	5.932	5.943	5.953	5.964	5.975	5.986	5.997	6.007	6.018	6.029
5.6	6.040	6.050	6.061	6.072	6.083	6.094	6.104	6.115	6.126	6.137
5.7	6.148	6.158	6.169	6.180	6.191	6.201	6.212	6.223	6.234	6.245
5.8	6.255	6.266	6.277	6.288	6.298	6.309	6.320	6.331	6.342	6.352
5.9	6.363	6.374	6.385	6.396	6.406	6.417	6.428	6.439	6.449	6.460
6.0	6.471	6.482	6.493	6.503	6.514	6.525	6.536	6.547	6.557	6.568
6.1	6.579	6.590	6.600	6.611	6.622	6.633	6.644	6.654	6.665	6.676
6.2	6.687	6.698	6.708	6.719	6.730	6.741	6.751	6.762	6.773	6.784
6.3	6.795	6.805	6.816	6.827	6.838	6.849	6.859	6.870	6.881	6.892
6.4	6.902	6.913	6.924	6.935	6.946	6.956	6.967	6.978	6.989	7.000
6.5	7.010	7.021	7.032	7.043	7.053	7.064	7.075	7.086	7.097	7.107
6.6	7.118	7.129	7.140	7.151	7.161	7.172	7.183	7.194	7.204	7.215
6.7	7.226	7.237	7.248	7.258	7.269	7.280	7.291	7.302	7.312	7.323
6.8	7.334	7.345	7.355	7.366	7.377	7.388	7.399	7.409	7.420	7.431
6.9	7.442	7.453	7.463	7.474	7.485	7.496	7.506	7.517	7.528	7.539
7.0	7.550	7.560	7.571	7.582	7.593	7.603	7.614	7.625	7.636	7.647
7.1	7.657	7.668	7.679	7.690	7.701	7.711	7.722	7.733	7.744	7.754
7.2	7.765	7.776	7.787	7.798	7.808	7.819	7.830	7.841	7.852	7.862
7.3	7.873	7.884	7.895	7.905	7.916	7.927	7.938	7.949	7.959	7.970
7.4	7.981	7.992	8.003	8.013	8.024	8.035	8.046	8.056	8.067	8.078
7.5	8.089	8.100	8.110	8.121	8.132	8.143	8.154	8.164	8.175	8.186
7.6	8.197	8.207	8.218	8.229	8.240	8.251	8.261	8.272	8.283	8.294
7.7	8.305	8.315	8.326	8.337	8.348	8.358	8.369	8.380	8.391	8.402
7.8	8.412	8.423	8.434	8.445	8.456	8.466	8.477	8.488	8.499	8.509
7.9	8.520	8.531	8.542	8.553	8.563	8.574	8.585	8.596	8.607	8.617
8.0	8.628	8.639	8.650	8.660	8.671	8.682	8.693	8.704	8.714	8.725
8.1	8.736	8.747	8.758	8.768	8.779	8.790	8.801	8.811	8.822	8.833
8.2	8.844	8.855	8.865	8.876	8.887	8.898	8.908	8.919	8.930	8.941
8.3	8.952	8.962	8.973	8.984	8.995	9.006	9.016	9.027	9.038	9.049
8.4	9.059	9.070	9.081	9.092	9.103	9.113	9.124	9.135	9.146	9.157
8.5	9.167	9.178	9.189	9.200	9.210	9.221	9.232	9.243	9.254	9.264
8.6	9.275	9.286	9.297	9.308	9.318	9.329	9.340	9.351	9.361	9.372
8.7	9.383	9.394	9.405	9.415	9.426	9.437	9.448	9.459	9.469	9.480
8.8	9.491	9.502	9.512	9.523	9.534	9.545	9.556	9.566	9.577	9.588
8.9	9.599	9.610	9.620	9.631	9.642	9.653	9.663	9.674	9.685	9.696
9.0	9.707	9.717	9.728	9.739	9.750	9.761	9.771	9.782	9.793	9.804
9.1	9.814	9.825	9.836	9.847	9.858	9.868	9.879	9.890	9.901	9.912
9.2	9.922	9.933	9.944	9.955	9.965	9.976	9.987	9.998	10.009	10.019
9.3	10.030	10.041	10.052	10.062	10.073	10.084	10.095	10.106	10.116	10.127
9.4	10.138	10.149	10.160	10.170	10.181	10.192	10.203	10.213	10.224	10.235
9.5	10.246	10.257	10.267	10.278	10.289	10.300	10.311	10.321	10.332	10.343
9.6	10.354	10.364	10.375	10.386	10.397	10.408	10.418	10.429	10.440	10.451
9.7	10.462	10.472	10.483	10.494	10.505	10.515	10.526	10.537	10.548	10.559
9.8	10.569	10.580	10.591	10.602	10.613	10.623	10.634	10.645	10.656	10.666
9.9	10.677	10.688	10.699	10.710	10.720	10.731	10.742	10.753	10.764	10.774

80 CONTRIBUTIONS TO HYDROLOGY OF UNITED STATES, 1917.

Discharge in second-feet per square mile into run-off in depth in inches per month of 30 days.

No.	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.011	0.022	0.033	0.045	0.056	0.067	0.078	0.089	0.100
.1	.112	.123	.134	.145	.156	.167	.179	.190	.201	.212
.2	.223	.234	.245	.257	.268	.279	.290	.301	.312	.324
.3	.335	.346	.357	.368	.379	.390	.402	.413	.424	.435
.4	.446	.457	.469	.480	.491	.502	.513	.524	.536	.547
.5	.558	.569	.580	.591	.602	.614	.625	.636	.647	.658
.6	.669	.681	.692	.703	.714	.725	.736	.748	.759	.770
.7	.781	.792	.803	.814	.826	.837	.848	.859	.870	.881
.8	.893	.904	.915	.926	.937	.948	.960	.971	.982	.993
.9	1.004	1.015	1.026	1.038	1.049	1.060	1.071	1.082	1.093	1.105
1.0	1.116	1.127	1.138	1.149	1.160	1.171	1.183	1.194	1.205	1.216
1.1	1.227	1.238	1.250	1.261	1.272	1.283	1.294	1.305	1.317	1.328
1.2	1.339	1.350	1.361	1.372	1.383	1.395	1.406	1.417	1.428	1.439
1.3	1.450	1.462	1.473	1.484	1.495	1.506	1.517	1.529	1.540	1.551
1.4	1.562	1.573	1.584	1.595	1.607	1.618	1.629	1.640	1.651	1.662
1.5	1.674	1.685	1.696	1.707	1.718	1.729	1.740	1.752	1.763	1.774
1.6	1.785	1.796	1.807	1.819	1.830	1.841	1.852	1.863	1.874	1.886
1.7	1.897	1.908	1.919	1.930	1.941	1.952	1.964	1.975	1.986	1.997
1.8	2.008	2.019	2.031	2.042	2.053	2.064	2.075	2.086	2.098	2.109
1.9	2.120	2.131	2.142	2.153	2.164	2.176	2.187	2.198	2.209	2.220
2.0	2.231	2.243	2.254	2.265	2.276	2.287	2.298	2.309	2.321	2.332
2.1	2.343	2.354	2.365	2.376	2.388	2.399	2.410	2.421	2.432	2.443
2.2	2.455	2.466	2.477	2.488	2.499	2.510	2.521	2.533	2.544	2.555
2.3	2.566	2.577	2.588	2.600	2.611	2.622	2.633	2.644	2.655	2.667
2.4	2.678	2.689	2.700	2.711	2.722	2.733	2.745	2.756	2.767	2.778
2.5	2.789	2.800	2.812	2.823	2.834	2.845	2.856	2.867	2.879	2.890
2.6	2.901	2.912	2.923	2.934	2.945	2.957	2.968	2.979	2.990	3.001
2.7	3.012	3.024	3.035	3.046	3.057	3.068	3.079	3.090	3.102	3.113
2.8	3.124	3.135	3.146	3.157	3.169	3.180	3.191	3.202	3.213	3.224
2.9	3.236	3.247	3.258	3.269	3.280	3.291	3.302	3.314	3.325	3.336
3.0	3.347	3.358	3.369	3.381	3.392	3.403	3.414	3.425	3.436	3.448
3.1	3.459	3.470	3.481	3.492	3.503	3.514	3.526	3.537	3.548	3.559
3.2	3.570	3.581	3.593	3.604	3.615	3.626	3.637	3.648	3.659	3.671
3.3	3.682	3.693	3.704	3.715	3.726	3.738	3.749	3.760	3.771	3.782
3.4	3.793	3.805	3.816	3.827	3.838	3.849	3.860	3.871	3.883	3.894
3.5	3.905	3.916	3.927	3.938	3.950	3.961	3.972	3.983	3.994	4.005
3.6	4.017	4.028	4.039	4.050	4.061	4.072	4.083	4.095	4.106	4.117
3.7	4.128	4.139	4.150	4.162	4.173	4.184	4.195	4.206	4.217	4.229
3.8	4.240	4.251	4.262	4.273	4.284	4.295	4.307	4.318	4.329	4.340
3.9	4.351	4.362	4.374	4.385	4.396	4.407	4.418	4.429	4.440	4.452
4.0	4.463	4.474	4.485	4.496	4.507	4.519	4.530	4.541	4.552	4.563
4.1	4.574	4.586	4.597	4.608	4.619	4.630	4.641	4.652	4.664	4.675
4.2	4.686	4.697	4.708	4.719	4.731	4.742	4.753	4.764	4.775	4.786
4.3	4.798	4.809	4.820	4.831	4.842	4.853	4.864	4.876	4.887	4.898
4.4	4.909	4.920	4.931	4.943	4.954	4.965	4.976	4.987	4.998	5.009
4.5	5.021	5.032	5.043	5.054	5.065	5.076	5.088	5.099	5.110	5.121
4.6	5.132	5.143	5.155	5.166	5.177	5.188	5.199	5.210	5.221	5.233
4.7	5.244	5.255	5.266	5.277	5.288	5.300	5.311	5.322	5.333	5.344
4.8	5.355	5.367	5.378	5.389	5.400	5.411	5.422	5.433	5.445	5.456
4.9	5.467	5.478	5.489	5.500	5.512	5.523	5.534	5.545	5.556	5.567

Discharge in second-feet per square mile into run-off in depth in inches per month of 30 days—Continued.

No.	0	1	2	3	4	5	6	7	8	9
5.0	5.579	5.590	5.601	5.612	5.623	5.634	5.645	5.657	5.668	5.679
5.1	5.690	5.701	5.712	5.724	5.735	5.746	5.757	5.768	5.779	5.790
5.2	5.802	5.813	5.824	5.835	5.846	5.857	5.869	5.880	5.891	5.902
5.3	5.913	5.924	5.936	5.947	5.958	5.969	5.980	5.991	6.002	6.014
5.4	6.025	6.036	6.047	6.058	6.069	6.081	6.092	6.103	6.114	6.125
5.5	6.136	6.148	6.159	6.170	6.181	6.192	6.203	6.214	6.226	6.237
5.6	6.248	6.259	6.270	6.281	6.293	6.304	6.315	6.326	6.337	6.348
5.7	6.359	6.371	6.382	6.393	6.404	6.415	6.426	6.438	6.449	6.460
5.8	6.471	6.482	6.493	6.505	6.516	6.527	6.538	6.549	6.560	6.571
5.9	6.583	6.594	6.605	6.616	6.627	6.638	6.650	6.661	6.672	6.683
6.0	6.694	6.705	6.717	6.728	6.739	6.750	6.761	6.772	6.783	6.795
6.1	6.806	6.817	6.828	6.839	6.850	6.862	6.873	6.884	6.895	6.906
6.2	6.917	6.928	6.940	6.951	6.962	6.973	6.984	6.995	7.007	7.018
6.3	7.029	7.040	7.051	7.062	7.074	7.085	7.096	7.107	7.118	7.129
6.4	7.140	7.152	7.163	7.174	7.185	7.196	7.207	7.219	7.230	7.241
6.5	7.252	7.263	7.274	7.286	7.297	7.308	7.319	7.330	7.341	7.352
6.6	7.364	7.375	7.386	7.397	7.408	7.419	7.431	7.442	7.453	7.464
6.7	7.475	7.486	7.498	7.509	7.520	7.531	7.542	7.553	7.564	7.576
6.8	7.587	7.598	7.609	7.620	7.631	7.643	7.654	7.665	7.676	7.687
6.9	7.698	7.709	7.721	7.732	7.743	7.754	7.765	7.776	7.788	7.799
7.0	7.810	7.821	7.832	7.843	7.855	7.866	7.877	7.888	7.899	7.910
7.1	7.921	7.933	7.944	7.955	7.966	7.977	7.988	8.000	8.011	8.022
7.2	8.033	8.044	8.055	8.067	8.078	8.089	8.100	8.111	8.122	8.133
7.3	8.145	8.156	8.167	8.178	8.189	8.200	8.212	8.223	8.234	8.245
7.4	8.256	8.267	8.278	8.290	8.301	8.312	8.323	8.334	8.345	8.357
7.5	8.368	8.379	8.390	8.401	8.412	8.424	8.435	8.446	8.457	8.468
7.6	8.479	8.490	8.502	8.513	8.524	8.535	8.546	8.557	8.569	8.580
7.7	8.591	8.602	8.613	8.624	8.636	8.647	8.658	8.669	8.680	8.691
7.8	8.702	8.714	8.725	8.736	8.747	8.758	8.769	8.781	8.792	8.803
7.9	8.814	8.825	8.836	8.848	8.859	8.870	8.881	8.892	8.903	8.914
8.0	8.926	8.937	8.948	8.959	8.970	8.981	8.993	9.004	9.015	9.026
8.1	9.037	9.048	9.059	9.071	9.082	9.093	9.104	9.115	9.126	9.138
8.2	9.149	9.160	9.171	9.182	9.193	9.205	9.216	9.227	9.238	9.249
8.3	9.260	9.271	9.283	9.294	9.305	9.316	9.327	9.338	9.350	9.361
8.4	9.372	9.383	9.394	9.405	9.417	9.428	9.439	9.450	9.461	9.472
8.5	9.483	9.495	9.506	9.517	9.528	9.539	9.550	9.562	9.573	9.584
8.6	9.595	9.606	9.617	9.628	9.640	9.651	9.662	9.673	9.684	9.695
8.7	9.707	9.718	9.729	9.740	9.751	9.762	9.774	9.785	9.796	9.807
8.8	9.818	9.829	9.840	9.852	9.863	9.874	9.885	9.896	9.907	9.919
8.9	9.930	9.941	9.952	9.963	9.974	9.986	9.997	10.008	10.019	10.030
9.0	10.041	10.052	10.064	10.075	10.086	10.097	10.108	10.119	10.131	10.142
9.1	10.153	10.164	10.175	10.186	10.197	10.209	10.220	10.231	10.242	10.253
9.2	10.264	10.276	10.287	10.298	10.309	10.320	10.331	10.343	10.354	10.365
9.3	10.376	10.387	10.398	10.409	10.421	10.432	10.443	10.454	10.465	10.476
9.4	10.488	10.499	10.510	10.521	10.532	10.543	10.555	10.566	10.577	10.588
9.5	10.599	10.610	10.621	10.633	10.644	10.655	10.666	10.677	10.688	10.700
9.6	10.711	10.722	10.733	10.744	10.755	10.767	10.778	10.789	10.800	10.811
9.7	10.822	10.833	10.845	10.856	10.867	10.878	10.889	10.900	10.912	10.923
9.8	10.934	10.945	10.956	10.967	10.978	10.990	11.001	11.012	11.023	11.034
9.9	11.045	11.057	11.068	11.079	11.090	11.101	11.112	11.124	11.135	11.146

Discharge in second-feet per square mile into run-off in depth in inches per month of 31 days.

No.	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.012	0.023	0.035	0.046	0.058	0.069	0.081	0.092	0.104
.1	.115	.127	.138	.150	.161	.173	.184	.196	.208	.219
.2	.231	.242	.254	.265	.277	.288	.300	.311	.323	.334
.3	.346	.357	.369	.380	.392	.404	.415	.427	.438	.450
.4	.461	.473	.484	.496	.507	.519	.530	.542	.553	.565
.5	.576	.588	.600	.611	.623	.634	.646	.657	.669	.680
.6	.692	.703	.715	.726	.738	.749	.761	.772	.784	.795
.7	.807	.819	.830	.842	.853	.865	.876	.888	.899	.911
.8	.922	.934	.945	.957	.968	.980	.991	1.003	1.015	1.026
.9	1.038	1.049	1.061	1.072	1.084	1.095	1.107	1.118	1.130	1.141
1.0	1.153	1.164	1.176	1.187	1.199	1.211	1.222	1.234	1.245	1.257
1.1	1.268	1.280	1.291	1.303	1.314	1.326	1.337	1.349	1.360	1.372
1.2	1.383	1.395	1.407	1.418	1.430	1.441	1.453	1.464	1.476	1.487
1.3	1.499	1.510	1.522	1.533	1.545	1.556	1.568	1.579	1.591	1.603
1.4	1.614	1.626	1.637	1.649	1.660	1.672	1.683	1.695	1.706	1.718
1.5	1.729	1.741	1.752	1.764	1.775	1.787	1.799	1.810	1.822	1.833
1.6	1.845	1.856	1.868	1.879	1.891	1.902	1.914	1.925	1.937	1.948
1.7	1.960	1.971	1.983	1.994	2.006	2.018	2.029	2.041	2.052	2.064
1.8	2.075	2.087	2.098	2.110	2.121	2.133	2.144	2.156	2.167	2.179
1.9	2.190	2.202	2.214	2.225	2.237	2.248	2.260	2.271	2.283	2.294
2.0	2.306	2.317	2.329	2.340	2.352	2.363	2.375	2.386	2.398	2.410
2.1	2.421	2.433	2.444	2.456	2.467	2.479	2.490	2.502	2.513	2.525
2.2	2.536	2.548	2.559	2.571	2.582	2.594	2.606	2.617	2.629	2.640
2.3	2.652	2.663	2.675	2.686	2.698	2.709	2.721	2.732	2.744	2.755
2.4	2.767	2.778	2.790	2.802	2.813	2.825	2.836	2.848	2.859	2.871
2.5	2.882	2.894	2.905	2.917	2.928	2.940	2.951	2.963	2.974	2.986
2.6	2.998	3.009	3.021	3.032	3.044	3.055	3.067	3.078	3.090	3.101
2.7	3.113	3.124	3.136	3.147	3.159	3.170	3.182	3.194	3.205	3.217
2.8	3.228	3.240	3.251	3.263	3.274	3.286	3.297	3.309	3.320	3.332
2.9	3.343	3.355	3.366	3.378	3.389	3.401	3.413	3.424	3.436	3.447
3.0	3.459	3.470	3.482	3.493	3.505	3.516	3.528	3.539	3.551	3.562
3.1	3.574	3.585	3.597	3.609	3.620	3.632	3.643	3.655	3.666	3.678
3.2	3.689	3.701	3.712	3.724	3.735	3.747	3.758	3.770	3.781	3.793
3.3	3.805	3.816	3.828	3.839	3.851	3.862	3.874	3.885	3.897	3.908
3.4	3.920	3.931	3.943	3.954	3.966	3.977	3.989	4.001	4.012	4.024
3.5	4.035	4.047	4.058	4.070	4.081	4.093	4.104	4.116	4.127	4.139
3.6	4.150	4.162	4.173	4.185	4.197	4.208	4.220	4.231	4.243	4.254
3.7	4.266	4.277	4.289	4.300	4.312	4.323	4.335	4.346	4.358	4.369
3.8	4.381	4.393	4.404	4.416	4.427	4.439	4.450	4.462	4.473	4.485
3.9	4.496	4.508	4.519	4.531	4.542	4.554	4.565	4.577	4.589	4.600
4.0	4.612	4.623	4.635	4.646	4.658	4.669	4.681	4.692	4.704	4.715
4.1	4.727	4.738	4.750	4.761	4.773	4.784	4.796	4.808	4.819	4.831
4.2	4.842	4.854	4.865	4.877	4.888	4.900	4.911	4.923	4.934	4.946
4.3	4.957	4.969	4.980	4.992	5.004	5.015	5.027	5.038	5.050	5.061
4.4	5.073	5.084	5.096	5.107	5.119	5.130	5.142	5.153	5.165	5.176
4.5	5.188	5.200	5.211	5.223	5.234	5.246	5.257	5.269	5.280	5.292
4.6	5.303	5.315	5.326	5.338	5.349	5.361	5.372	5.384	5.396	5.407
4.7	5.419	5.430	5.442	5.453	5.465	5.476	5.488	5.499	5.511	5.522
4.8	5.534	5.545	5.557	5.568	5.580	5.592	5.603	5.615	5.626	5.638
4.9	5.649	5.661	5.672	5.684	5.695	5.707	5.718	5.730	5.741	5.753

Discharge in second-feet per square mile into run-off in depth in inches per month of 31 days—Continued.

No.	0	1	2	3	4	5	6	7	8	9
5.0	5.764	5.776	5.788	5.799	5.811	5.822	5.834	5.845	5.857	5.868
5.1	5.880	5.891	5.903	5.914	5.926	5.937	5.949	5.960	5.972	5.983
5.2	5.995	6.007	6.018	6.030	6.041	6.053	6.064	6.076	6.087	6.099
5.3	6.110	6.122	6.133	6.145	6.156	6.168	6.179	6.191	6.203	6.214
5.4	6.226	6.237	6.249	6.260	6.272	6.283	6.295	6.306	6.318	6.329
5.5	6.341	6.352	6.364	6.375	6.387	6.399	6.410	6.422	6.433	6.445
5.6	6.456	6.468	6.479	6.491	6.502	6.514	6.525	6.537	6.548	6.560
5.7	6.571	6.583	6.595	6.606	6.618	6.629	6.641	6.652	6.664	6.675
5.8	6.687	6.698	6.710	6.721	6.733	6.744	6.756	6.767	6.779	6.791
5.9	6.802	6.814	6.825	6.837	6.848	6.860	6.871	6.883	6.894	6.906
6.0	6.917	6.929	6.940	6.952	6.963	6.975	6.987	6.998	7.010	7.021
6.1	7.033	7.044	7.056	7.067	7.079	7.090	7.102	7.113	7.125	7.136
6.2	7.148	7.159	7.171	7.183	7.194	7.206	7.217	7.229	7.240	7.252
6.3	7.263	7.274	7.286	7.298	7.309	7.321	7.332	7.344	7.355	7.367
6.4	7.378	7.389	7.401	7.413	7.425	7.436	7.448	7.459	7.471	7.482
6.5	7.494	7.505	7.517	7.528	7.540	7.551	7.563	7.574	7.586	7.598
6.6	7.609	7.620	7.632	7.644	7.655	7.667	7.678	7.690	7.701	7.713
6.7	7.724	7.735	7.747	7.759	7.770	7.782	7.794	7.805	7.817	7.828
6.8	7.840	7.851	7.863	7.874	7.886	7.897	7.909	7.920	7.932	7.943
6.9	7.955	7.966	7.978	7.990	8.001	8.013	8.024	8.036	8.047	8.059
7.0	8.070	8.081	8.093	8.105	8.116	8.128	8.139	8.151	8.162	8.174
7.1	8.186	8.197	8.209	8.220	8.232	8.243	8.255	8.266	8.278	8.289
7.2	8.301	8.312	8.324	8.335	8.347	8.358	8.370	8.382	8.393	8.405
7.3	8.416	8.428	8.439	8.451	8.462	8.474	8.485	8.497	8.508	8.520
7.4	8.531	8.543	8.554	8.566	8.578	8.589	8.601	8.612	8.624	8.635
7.5	8.647	8.658	8.670	8.681	8.693	8.704	8.716	8.727	8.739	8.750
7.6	8.762	8.773	8.785	8.797	8.808	8.820	8.831	8.843	8.854	8.866
7.7	8.877	8.889	8.900	8.912	8.923	8.935	8.946	8.958	8.969	8.981
7.8	8.993	9.004	9.016	9.027	9.039	9.050	9.062	9.073	9.085	9.096
7.9	9.108	9.119	9.131	9.142	9.154	9.165	9.177	9.189	9.200	9.212
8.0	9.223	9.235	9.246	9.258	9.269	9.281	9.292	9.304	9.315	9.327
8.1	9.338	9.350	9.361	9.373	9.385	9.396	9.408	9.419	9.431	9.442
8.2	9.454	9.465	9.477	9.488	9.500	9.511	9.523	9.534	9.546	9.557
8.3	9.569	9.581	9.592	9.604	9.615	9.627	9.638	9.650	9.661	9.673
8.4	9.684	9.696	9.707	9.719	9.730	9.742	9.753	9.765	9.777	9.788
8.5	9.800	9.811	9.823	9.834	9.846	9.857	9.869	9.880	9.892	9.903
8.6	9.915	9.926	9.938	9.949	9.961	9.972	9.984	9.996	10.007	10.019
8.7	10.030	10.042	10.053	10.065	10.076	10.088	10.099	10.111	10.122	10.134
8.8	10.145	10.157	10.168	10.180	10.192	10.203	10.215	10.226	10.238	10.249
8.9	10.261	10.272	10.284	10.295	10.307	10.318	10.330	10.341	10.353	10.364
9.0	10.376	10.388	10.399	10.411	10.422	10.434	10.445	10.457	10.468	10.480
9.1	10.491	10.503	10.514	10.526	10.537	10.549	10.560	10.572	10.584	10.595
9.2	10.607	10.618	10.630	10.641	10.653	10.664	10.676	10.687	10.699	10.710
9.3	10.722	10.733	10.745	10.756	10.768	10.780	10.791	10.803	10.814	10.826
9.4	10.837	10.849	10.860	10.872	10.883	10.895	10.906	10.918	10.929	10.941
9.5	10.952	10.964	10.976	10.987	10.999	11.010	11.022	11.033	11.045	11.056
9.6	11.068	11.079	11.091	11.102	11.114	11.125	11.137	11.148	11.160	11.172
9.7	11.183	11.195	11.206	11.218	11.229	11.241	11.252	11.264	11.275	11.287
9.8	11.298	11.310	11.321	11.333	11.344	11.356	11.367	11.379	11.391	11.402
9.9	11.414	11.425	11.437	11.448	11.460	11.471	11.483	11.494	11.506	11.517

Discharge in second-feet into run-off in acre-feet per month of 28 days.

No.	0	1	2	3	4	5	6	7	8	9
0	0.000	56	111	167	222	278	333	389	444	500
1	555.372	611	666	722	778	833	889	944	1,000	1,055
2	1,110.744	1,166	1,222	1,277	1,333	1,388	1,444	1,500	1,555	1,611
3	1,666.116	1,722	1,777	1,833	1,888	1,944	1,999	2,055	2,110	2,166
4	2,221.488	2,277	2,333	2,388	2,444	2,499	2,555	2,610	2,666	2,721
5	2,776.859	2,832	2,888	2,943	2,999	3,055	3,110	3,166	3,221	3,277
6	3,332.231	3,388	3,443	3,499	3,554	3,610	3,665	3,721	3,777	3,832
7	3,887.603	3,943	3,999	4,054	4,110	4,165	4,221	4,276	4,332	4,387
8	4,442.975	4,499	4,554	4,610	4,665	4,721	4,776	4,832	4,887	4,943
9	4,998.347	5,054	5,109	5,165	5,220	5,276	5,332	5,387	5,443	5,498
10	5,553.719	5,609	5,665	5,720	5,776	5,831	5,887	5,942	5,998	6,054
11	6,109.091	6,165	6,220	6,276	6,331	6,387	6,442	6,498	6,553	6,609
12	6,664.463	6,720	6,776	6,831	6,887	6,943	6,998	7,053	7,109	7,164
13	7,219.834	7,275	7,331	7,386	7,442	7,498	7,553	7,609	7,664	7,720
14	7,775.206	7,831	7,886	7,942	7,997	8,053	8,108	8,164	8,220	8,275
15	8,330.578	8,386	8,442	8,497	8,553	8,608	8,663	8,719	8,775	8,830
16	8,885.950	8,941	8,997	9,053	9,108	9,164	9,219	9,275	9,330	9,386
17	9,441.322	9,497	9,552	9,608	9,663	9,719	9,774	9,830	9,886	9,941
18	9,996.694	10,052	10,108	10,163	10,219	10,274	10,330	10,385	10,441	10,497
19	10,552.066	10,608	10,663	10,719	10,774	10,830	10,885	10,941	10,996	11,052
20	11,107.438	11,163	11,219	11,274	11,330	11,385	11,441	11,496	11,552	11,607
21	11,662.809	11,718	11,774	11,829	11,885	11,940	11,996	12,052	12,107	12,163
22	12,218.181	12,274	12,329	12,385	12,440	12,496	12,551	12,607	12,662	12,718
23	12,773.553	12,829	12,885	12,940	12,996	13,051	13,107	13,162	13,218	13,273
24	13,328.925	13,384	13,440	13,496	13,551	13,607	13,662	13,718	13,773	13,829
25	13,884.297	13,940	13,995	14,051	14,106	14,162	14,218	14,273	14,329	14,384
26	14,439.669	14,495	14,551	14,606	14,662	14,717	14,773	14,828	14,884	14,940
27	14,995.041	15,051	15,106	15,162	15,217	15,273	15,328	15,384	15,439	15,495
28	15,550.413	15,606	15,661	15,717	15,773	15,828	15,884	15,939	15,995	16,050
29	16,105.785	16,161	16,217	16,272	16,328	16,383	16,439	16,495	16,550	16,606
30	16,661.156	16,717	16,772	16,828	16,883	16,939	16,994	17,050	17,105	17,161
31	17,216.528	17,272	17,328	17,383	17,439	17,494	17,550	17,605	17,661	17,716
32	17,771.900	17,827	17,883	17,939	17,994	18,050	18,105	18,161	18,216	18,272
33	18,327.272	18,383	18,438	18,494	18,549	18,605	18,660	18,716	18,772	18,827
34	18,882.644	18,938	18,994	19,049	19,105	19,160	19,216	19,271	19,327	19,382
35	19,438.016	19,494	19,549	19,605	19,660	19,716	19,771	19,827	19,882	19,938
36	19,993.388	20,049	20,104	20,160	20,216	20,271	20,327	20,382	20,438	20,493
37	20,548.760	20,604	20,660	20,715	20,771	20,826	20,882	20,938	20,993	21,049
38	21,104.131	21,160	21,215	21,271	21,326	21,382	21,437	21,493	21,548	21,604
39	21,659.503	21,715	21,771	21,826	21,882	21,937	21,993	22,048	22,104	22,159
40	22,214.875	22,270	22,326	22,381	22,437	22,493	22,548	22,604	22,659	22,715
41	22,770.247	22,826	22,881	22,937	22,992	23,048	23,103	23,159	23,215	23,270
42	23,325.619	23,381	23,437	23,492	23,548	23,603	23,659	23,714	23,770	23,825
43	23,880.991	23,937	23,992	24,048	24,103	24,159	24,214	24,270	24,325	24,381
44	24,436.363	24,492	24,547	24,603	24,659	24,714	24,770	24,825	24,881	24,936
45	24,991.735	25,047	25,103	25,158	25,214	25,269	25,325	25,380	25,436	25,492
46	25,547.106	25,603	25,658	25,714	25,769	25,825	25,880	25,936	25,991	26,047
47	26,102.478	26,158	26,214	26,269	26,325	26,380	26,436	26,491	26,547	26,602
48	26,657.850	26,713	26,769	26,824	26,880	26,936	26,991	27,047	27,102	27,158
49	27,213.222	27,269	27,324	27,380	27,435	27,491	27,546	27,602	27,658	27,713

Discharge in second-feet into run-off in acre-feet per month of 28 days—Continued.

No.	0	1	2	3	4	5	6	7	8	9
50	27, 768. 594	27, 824	27, 880	27, 935	27, 991	28, 046	28, 102	28, 157	28, 213	28, 268
51	28, 323. 966	28, 380	28, 435	28, 491	28, 546	28, 602	28, 657	28, 713	28, 768	28, 824
52	28, 879. 338	28, 935	28, 990	29, 046	29, 101	29, 157	29, 213	29, 268	29, 324	29, 379
53	29, 434. 710	29, 490	29, 546	29, 601	29, 657	29, 712	29, 768	29, 823	29, 879	29, 935
54	29, 990. 082	30, 046	30, 101	30, 157	30, 212	30, 268	30, 323	30, 379	30, 434	30, 490
55	30, 545. 453	30, 601	30, 657	30, 712	30, 768	30, 823	30, 879	30, 934	30, 990	31, 045
56	31, 100. 825	31, 156	31, 212	31, 267	31, 323	31, 379	31, 434	31, 490	31, 545	31, 601
57	31, 656. 197	31, 712	31, 767	31, 823	31, 878	31, 934	31, 989	32, 045	32, 100	32, 156
58	32, 211. 569	32, 267	32, 323	32, 378	32, 434	32, 489	32, 545	32, 600	32, 656	32, 711
59	32, 766. 941	32, 822	32, 878	32, 934	32, 989	33, 045	33, 100	33, 156	33, 211	33, 267
60	33, 322. 313	33, 378	33, 433	33, 489	33, 544	33, 600	33, 656	33, 711	33, 767	33, 822
61	33, 877. 685	33, 933	33, 989	34, 044	34, 100	34, 155	34, 211	34, 266	34, 322	34, 378
62	34, 433. 057	34, 489	34, 544	34, 600	34, 655	34, 711	34, 766	34, 822	34, 877	34, 933
63	34, 988. 428	35, 044	35, 100	35, 155	35, 211	35, 266	35, 322	35, 377	35, 433	35, 488
64	35, 543. 800	35, 599	35, 655	35, 710	35, 766	35, 821	35, 877	35, 933	35, 988	36, 044
65	36, 099. 172	36, 155	36, 210	36, 266	36, 321	36, 377	36, 432	36, 488	36, 543	36, 599
66	36, 654. 544	36, 710	36, 766	36, 821	36, 877	36, 932	36, 988	37, 043	37, 099	37, 154
67	37, 209. 916	37, 265	37, 321	37, 377	37, 432	37, 488	37, 543	37, 599	37, 654	37, 710
68	37, 765. 288	37, 821	37, 876	37, 932	37, 987	38, 043	38, 099	38, 154	38, 210	38, 265
69	38, 320. 660	38, 376	38, 432	38, 487	38, 543	38, 598	38, 654	38, 709	38, 765	38, 820
70	38, 876. 032	38, 932	38, 987	39, 043	39, 098	39, 154	39, 209	39, 265	39, 320	39, 376
71	39, 431. 403	39, 487	39, 542	39, 598	39, 654	39, 709	39, 765	39, 820	39, 876	39, 931
72	39, 986. 775	40, 042	40, 098	40, 153	40, 209	40, 264	40, 320	40, 376	40, 431	40, 487
73	40, 542. 147	40, 598	40, 653	40, 709	40, 764	40, 820	40, 875	40, 931	40, 986	41, 042
74	41, 097. 519	41, 153	41, 209	41, 264	41, 320	41, 375	41, 431	41, 486	41, 542	41, 597
75	41, 652. 891	41, 708	41, 764	41, 820	41, 875	41, 931	41, 986	42, 042	42, 097	42, 153
76	42, 208. 263	42, 264	42, 319	42, 375	42, 430	42, 486	42, 541	42, 597	42, 653	42, 708
77	42, 763. 635	42, 819	42, 875	42, 930	42, 986	43, 041	43, 097	43, 152	43, 208	43, 263
78	43, 319. 007	43, 375	43, 430	43, 486	43, 541	43, 597	43, 652	43, 708	43, 763	43, 819
79	43, 874. 379	43, 930	43, 985	44, 041	44, 097	44, 152	44, 208	44, 263	44, 319	44, 374
80	44, 429. 750	44, 485	44, 541	44, 596	44, 652	44, 707	44, 763	44, 819	44, 874	44, 930
81	44, 985. 122	45, 041	45, 096	45, 152	45, 207	45, 263	45, 318	45, 374	45, 429	45, 485
82	45, 540. 494	45, 596	45, 652	45, 707	45, 763	45, 818	45, 874	45, 929	45, 985	46, 040
83	46, 095. 866	46, 151	46, 207	46, 262	46, 318	46, 374	46, 429	46, 485	46, 540	46, 596
84	46, 651. 238	46, 707	46, 762	46, 818	46, 873	46, 929	46, 984	47, 040	47, 096	47, 151
85	47, 206. 610	47, 262	47, 318	47, 373	47, 429	47, 484	47, 540	47, 595	47, 651	47, 706
86	47, 761. 982	47, 818	47, 873	47, 929	47, 984	48, 040	48, 095	48, 151	48, 206	48, 262
87	48, 317. 354	48, 373	48, 428	48, 484	48, 540	48, 595	48, 651	48, 706	48, 762	48, 817
88	48, 872. 725	48, 928	48, 984	49, 039	49, 095	49, 150	49, 206	49, 261	49, 317	49, 373
89	49, 428. 097	49, 484	49, 539	49, 595	49, 650	49, 706	49, 761	49, 817	49, 872	49, 928
90	49, 983. 469	50, 039	50, 095	50, 150	50, 206	50, 261	50, 317	50, 372	50, 428	50, 483
91	50, 538. 841	50, 594	50, 650	50, 705	50, 761	50, 817	50, 872	50, 928	50, 983	51, 039
92	51, 094. 213	51, 150	51, 205	51, 261	51, 316	51, 372	51, 427	51, 483	51, 539	51, 594
93	51, 649. 585	51, 705	51, 761	51, 816	51, 872	51, 927	51, 983	52, 038	52, 094	52, 149
94	52, 204. 957	52, 260	52, 316	52, 372	52, 427	52, 483	52, 538	52, 594	52, 649	52, 705
95	52, 760. 329	52, 816	52, 871	52, 927	52, 982	53, 038	53, 094	53, 149	53, 205	53, 260
96	53, 315. 700	53, 371	53, 427	53, 482	53, 538	53, 593	53, 649	53, 704	53, 760	53, 816
97	53, 871. 072	53, 927	53, 982	54, 038	54, 093	54, 149	54, 204	54, 260	54, 315	54, 371
98	54, 426. 444	54, 482	54, 538	54, 593	54, 649	54, 704	54, 760	54, 815	54, 871	54, 926
99	54, 981. 816	55, 037	55, 093	55, 148	55, 204	55, 260	55, 315	55, 371	55, 426	55, 482

Discharge in second-feet into run-off in acre-feet per month of 29 days.

No.	0	1	2	3	4	5	6	7	8	9
0	0.000	58	115	173	230	288	345	403	460	518
1	575.207	633	690	748	805	863	920	978	1,035	1,093
2	1,150.413	1,208	1,265	1,323	1,380	1,438	1,496	1,553	1,611	1,668
3	1,725.620	1,783	1,841	1,898	1,956	2,013	2,071	2,128	2,186	2,243
4	2,300.826	2,358	2,416	2,473	2,531	2,588	2,646	2,703	2,761	2,819
5	2,876.033	2,934	2,991	3,049	3,106	3,164	3,221	3,279	3,336	3,394
6	3,451.240	3,509	3,566	3,624	3,681	3,739	3,796	3,854	3,911	3,969
7	4,026.446	4,084	4,141	4,199	4,257	4,314	4,372	4,429	4,487	4,544
8	4,601.653	4,659	4,717	4,774	4,832	4,889	4,947	5,004	5,062	5,119
9	5,176.859	5,234	5,292	5,349	5,407	5,464	5,522	5,580	5,637	5,695
10	5,752.066	5,810	5,867	5,925	5,982	6,040	6,097	6,155	6,212	6,270
11	6,327.272	6,385	6,442	6,500	6,557	6,615	6,672	6,730	6,787	6,845
12	6,902.479	6,960	7,018	7,075	7,133	7,190	7,248	7,305	7,363	7,420
13	7,477.686	7,535	7,593	7,650	7,708	7,765	7,823	7,880	7,938	7,995
14	8,052.892	8,110	8,168	8,225	8,283	8,340	8,398	8,456	8,513	8,571
15	8,628.099	8,686	8,743	8,801	8,858	8,916	8,973	9,031	9,088	9,146
16	9,203.305	9,261	9,318	9,376	9,433	9,491	9,548	9,606	9,663	9,721
17	9,778.512	9,836	9,894	9,951	10,009	10,066	10,124	10,181	10,239	10,296
18	10,353.719	10,411	10,469	10,526	10,584	10,641	10,699	10,756	10,814	10,871
19	10,928.925	10,986	11,044	11,101	11,159	11,217	11,274	11,332	11,389	11,447
20	11,504.132	11,562	11,619	11,677	11,734	11,792	11,849	11,907	11,964	12,022
21	12,079.338	12,137	12,194	12,252	12,309	12,367	12,424	12,482	12,540	12,597
22	12,654.545	12,712	12,770	12,827	12,885	12,942	13,000	13,057	13,115	13,172
23	13,229.752	13,287	13,345	13,402	13,460	13,517	13,575	13,632	13,690	13,747
24	13,804.958	13,862	13,920	13,978	14,035	14,093	14,150	14,208	14,265	14,323
25	14,390.165	14,438	14,495	14,553	14,610	14,668	14,725	14,783	14,840	14,898
26	14,955.371	15,013	15,070	15,128	15,185	15,243	15,300	15,358	15,416	15,473
27	15,530.578	15,588	15,646	15,703	15,761	15,818	15,876	15,933	15,991	16,048
28	16,105.785	16,163	16,221	16,278	16,336	16,393	16,451	16,508	16,566	16,623
29	16,680.991	16,739	16,796	16,854	16,911	16,969	17,026	17,084	17,141	17,199
30	17,256.198	17,314	17,371	17,429	17,486	17,544	17,601	17,659	17,716	17,774
31	17,831.404	17,889	17,946	18,004	18,061	18,119	18,177	18,234	18,292	18,349
32	18,406.611	18,464	18,522	18,579	18,637	18,694	18,752	18,809	18,867	18,924
33	18,981.817	19,039	19,097	19,154	19,212	19,269	19,327	19,384	19,442	19,500
34	19,557.024	19,615	19,672	19,730	19,787	19,845	19,902	19,960	20,017	20,075
35	20,132.231	20,190	20,247	20,305	20,362	20,420	20,477	20,535	20,592	20,650
36	20,707.437	20,765	20,822	20,880	20,938	20,995	21,053	21,110	21,168	21,225
37	21,282.644	21,340	21,398	21,455	21,513	21,570	21,628	21,685	21,743	21,800
38	21,857.850	21,915	21,973	22,030	22,088	22,145	22,203	22,260	22,318	22,376
39	22,433.057	22,491	22,548	22,606	22,663	22,721	22,778	22,836	22,893	22,951
40	23,008.264	23,066	23,123	23,181	23,238	23,296	23,353	23,411	23,468	23,526
41	23,583.470	23,641	23,699	23,756	23,814	23,871	23,929	23,986	24,044	24,101
42	24,158.677	24,216	24,274	24,331	24,389	24,446	24,504	24,561	24,619	24,676
43	24,733.883	24,791	24,849	24,906	24,964	25,021	25,079	25,137	25,194	25,252
44	25,309.090	25,367	25,424	25,482	25,539	25,597	25,654	25,712	25,769	25,827
45	25,884.297	25,942	25,999	26,057	26,114	26,172	26,229	26,287	26,344	26,402
46	26,459.503	26,517	26,575	26,632	26,690	26,747	26,805	26,862	26,920	26,977
47	27,034.710	27,092	27,150	27,207	27,265	27,322	27,380	27,437	27,495	27,552
48	27,609.916	27,667	27,725	27,782	27,840	27,898	27,955	28,013	28,070	28,128
49	28,185.123	28,243	28,300	28,358	28,415	28,473	28,530	28,588	28,645	28,703

Discharge in second-feet into run-off in acre-feet per month of 29 days—Continued.

No.	0	1	2	3	4	5	6	7	8	9
50	28, 760. 330	28, 818	28, 875	28, 933	28, 990	29, 048	29, 105	29, 163	29, 220	29, 278
51	29, 335. 536	29, 393	29, 451	29, 508	29, 566	29, 623	29, 681	29, 738	29, 796	29, 853
52	29, 910. 743	29, 968	30, 026	30, 083	30, 141	30, 198	30, 256	30, 313	30, 371	30, 428
53	30, 485. 949	30, 543	30, 601	30, 659	30, 716	30, 774	30, 831	30, 889	30, 946	31, 004
54	31, 061. 156	31, 119	31, 176	31, 234	31, 291	31, 349	31, 406	31, 464	31, 521	31, 579
55	31, 636. 362	31, 694	31, 751	31, 809	31, 866	31, 924	31, 981	32, 039	32, 097	32, 154
56	32, 211. 569	32, 269	32, 327	32, 384	32, 442	32, 499	32, 557	32, 614	32, 672	32, 729
57	32, 786. 776	32, 844	32, 902	32, 959	33, 017	33, 074	33, 132	33, 189	33, 247	33, 304
58	33, 361. 982	33, 420	33, 477	33, 535	33, 592	33, 650	33, 707	33, 765	33, 822	33, 880
59	33, 937. 189	33, 995	34, 052	34, 110	34, 167	34, 225	34, 282	34, 340	34, 397	34, 455
60	34, 512. 395	34, 570	34, 627	34, 685	34, 742	34, 800	34, 858	34, 915	34, 973	35, 030
61	35, 087. 602	35, 145	35, 203	35, 260	35, 318	35, 375	35, 433	35, 490	35, 548	35, 605
62	35, 662. 809	35, 720	35, 778	35, 835	35, 893	35, 950	36, 008	36, 065	36, 123	36, 180
63	36, 238. 015	36, 296	36, 353	36, 411	36, 468	36, 526	36, 583	36, 641	36, 698	36, 756
64	36, 813. 222	36, 871	36, 928	36, 986	37, 043	37, 101	37, 158	37, 216	37, 273	37, 331
65	37, 388. 428	37, 446	37, 503	37, 561	37, 619	37, 676	37, 734	37, 791	37, 849	37, 906
66	37, 963. 635	38, 021	38, 079	38, 136	38, 194	38, 251	38, 309	38, 366	38, 424	38, 481
67	38, 538. 842	38, 596	38, 654	38, 711	38, 769	38, 826	38, 884	38, 941	38, 999	39, 057
68	39, 114. 048	39, 172	39, 229	39, 287	39, 344	39, 402	39, 459	39, 517	39, 575	39, 632
69	39, 689. 255	39, 747	39, 804	39, 862	39, 919	39, 977	40, 034	40, 092	40, 149	40, 207
70	40, 264. 461	40, 322	40, 380	40, 437	40, 495	40, 552	40, 610	40, 667	40, 725	40, 782
71	40, 839. 668	40, 897	40, 955	41, 012	41, 070	41, 127	41, 185	41, 242	41, 300	41, 357
72	41, 414. 874	41, 472	41, 530	41, 587	41, 645	41, 702	41, 760	41, 818	41, 875	41, 933
73	41, 990. 081	42, 048	42, 105	42, 163	42, 220	42, 278	42, 335	42, 393	42, 450	42, 508
74	42, 565. 288	42, 623	42, 680	42, 738	42, 795	42, 853	42, 910	42, 968	43, 025	43, 083
75	43, 140. 494	43, 198	43, 256	43, 313	43, 371	43, 428	43, 486	43, 543	43, 601	43, 658
76	43, 715. 701	43, 773	43, 831	43, 888	43, 946	44, 003	44, 061	44, 118	44, 176	44, 233
77	44, 290. 907	44, 348	44, 406	44, 463	44, 521	44, 579	44, 636	44, 694	44, 751	44, 809
78	44, 866. 114	44, 924	44, 981	45, 039	45, 096	45, 154	45, 211	45, 269	45, 326	45, 384
79	45, 441. 321	45, 499	45, 556	45, 614	45, 671	45, 729	45, 786	45, 844	45, 901	45, 959
80	46, 016. 527	46, 074	46, 132	46, 189	46, 247	46, 304	46, 362	46, 419	46, 477	46, 534
81	46, 591. 734	46, 649	46, 707	46, 764	46, 822	46, 879	46, 937	46, 994	47, 052	47, 109
82	47, 166. 940	47, 224	47, 282	47, 340	47, 397	47, 455	47, 512	47, 570	47, 627	47, 685
83	47, 742. 147	47, 800	47, 857	47, 915	47, 972	48, 030	48, 087	48, 145	48, 202	48, 260
84	48, 317. 354	48, 375	48, 432	48, 490	48, 547	48, 605	48, 662	48, 720	48, 778	48, 835
85	48, 892. 560	48, 950	49, 008	49, 065	49, 123	49, 180	49, 238	49, 295	49, 353	49, 410
86	49, 467. 767	49, 525	49, 583	49, 640	49, 698	49, 755	49, 813	49, 870	49, 928	49, 985
87	50, 042. 973	50, 100	50, 158	50, 216	50, 273	50, 331	50, 388	50, 446	50, 503	50, 561
88	50, 618. 180	50, 676	50, 733	50, 791	50, 848	50, 906	50, 963	51, 021	51, 078	51, 136
89	51, 193. 387	51, 251	51, 308	51, 366	51, 423	51, 481	51, 539	51, 596	51, 654	51, 711
90	51, 768. 593	51, 826	51, 884	51, 941	51, 999	52, 056	52, 114	52, 171	52, 229	52, 286
91	52, 343. 800	52, 401	52, 459	52, 516	52, 574	52, 631	52, 689	52, 746	52, 804	52, 861
92	52, 919. 006	52, 977	53, 034	53, 092	53, 149	53, 207	53, 264	53, 322	53, 379	53, 437
93	53, 494. 213	53, 552	53, 609	53, 667	53, 724	53, 782	53, 839	53, 897	53, 954	54, 012
94	54, 069. 419	54, 127	54, 184	54, 242	54, 300	54, 357	54, 415	54, 472	54, 530	54, 587
95	54, 644. 626	54, 702	54, 760	54, 817	54, 875	54, 932	54, 990	55, 047	55, 105	55, 162
96	55, 219. 833	55, 277	55, 335	55, 392	55, 450	55, 507	55, 565	55, 622	55, 680	55, 738
97	55, 795. 039	55, 853	55, 910	55, 968	56, 025	56, 083	56, 140	56, 198	56, 256	56, 313
98	56, 370. 246	56, 428	56, 485	56, 543	56, 600	56, 658	56, 715	56, 773	56, 830	56, 888
99	56, 945. 452	57, 003	57, 060	57, 118	57, 176	57, 233	57, 291	57, 348	57, 406	57, 463

Discharge in second-feet into run-off in acre-feet per month of 30 days.

No.	0	1	2	3	4	5	6	7	8	9
0	0.000	60	119	179	238	298	357	417	476	536
1	595.041	655	714	774	833	893	952	1,012	1,071	1,131
2	1,190.083	1,250	1,309	1,369	1,428	1,488	1,547	1,607	1,666	1,726
3	1,785.124	1,845	1,904	1,964	2,023	2,083	2,142	2,202	2,261	2,321
4	2,380.165	2,440	2,499	2,559	2,618	2,678	2,737	2,797	2,856	2,916
5	2,975.206	3,035	3,094	3,154	3,213	3,273	3,332	3,392	3,451	3,511
6	3,570.248	3,630	3,689	3,749	3,808	3,868	3,927	3,987	4,046	4,106
7	4,165.289	4,225	4,284	4,344	4,403	4,463	4,522	4,582	4,641	4,701
8	4,760.330	4,820	4,879	4,939	4,998	5,058	5,117	5,177	5,236	5,296
9	5,355.372	5,415	5,474	5,534	5,593	5,653	5,712	5,772	5,831	5,891
10	5,950.413	6,010	6,069	6,129	6,188	6,248	6,307	6,367	6,426	6,486
11	6,545.454	6,605	6,664	6,724	6,783	6,843	6,902	6,962	7,021	7,081
12	7,140.496	7,200	7,260	7,319	7,379	7,438	7,498	7,557	7,617	7,676
13	7,735.537	7,795	7,855	7,914	7,974	8,033	8,093	8,152	8,212	8,271
14	8,330.578	8,390	8,450	8,509	8,569	8,628	8,688	8,747	8,807	8,866
15	8,925.620	8,985	9,045	9,104	9,164	9,223	9,283	9,342	9,402	9,461
16	9,520.661	9,580	9,640	9,699	9,759	9,818	9,878	9,937	9,997	10,056
17	10,115.702	10,175	10,235	10,294	10,354	10,413	10,473	10,532	10,592	10,651
18	10,710.743	10,770	10,830	10,889	10,949	11,008	11,068	11,127	11,187	11,246
19	11,305.785	11,365	11,425	11,484	11,544	11,603	11,663	11,722	11,782	11,841
20	11,900.826	11,960	12,020	12,079	12,139	12,198	12,258	12,317	12,377	12,436
21	12,495.867	12,555	12,615	12,674	12,734	12,793	12,853	12,912	12,972	13,031
22	13,090.909	13,150	13,210	13,269	13,329	13,388	13,448	13,507	13,567	13,626
23	13,685.950	13,745	13,805	13,864	13,924	13,983	14,043	14,102	14,162	14,221
24	14,280.991	14,340	14,400	14,460	14,519	14,579	14,638	14,698	14,757	14,817
25	14,876.032	14,936	14,995	15,055	15,114	15,174	15,233	15,293	15,352	15,412
26	15,471.074	15,531	15,590	15,650	15,709	15,769	15,828	15,888	15,947	16,007
27	16,066.115	16,126	16,185	16,245	16,304	16,364	16,423	16,483	16,542	16,602
28	16,661.156	16,721	16,780	16,840	16,899	16,959	17,018	17,078	17,137	17,197
29	17,256.198	17,316	17,375	17,435	17,494	17,554	17,613	17,673	17,732	17,792
30	17,851.239	17,911	17,970	18,030	18,089	18,149	18,208	18,268	18,327	18,387
31	18,446.280	18,506	18,565	18,625	18,684	18,744	18,803	18,863	18,922	18,982
32	19,041.322	19,101	19,160	19,220	19,279	19,339	19,398	19,458	19,517	19,577
33	19,636.363	19,696	19,755	19,815	19,874	19,934	19,993	20,053	20,112	20,172
34	20,231.404	20,291	20,350	20,410	20,469	20,529	20,588	20,648	20,707	20,767
35	20,826.446	20,886	20,945	21,005	21,064	21,124	21,183	21,243	21,302	21,362
36	21,421.487	21,481	21,540	21,600	21,660	21,719	21,779	21,838	21,898	21,957
37	22,016.528	22,076	22,136	22,195	22,255	22,314	22,374	22,433	22,493	22,552
38	22,611.569	22,671	22,731	22,790	22,850	22,909	22,969	23,028	23,088	23,147
39	23,206.611	23,266	23,326	23,385	23,445	23,504	23,564	23,623	23,683	23,742
40	23,801.652	23,861	23,921	23,980	24,040	24,099	24,159	24,218	24,278	24,337
41	24,396.693	24,456	24,516	24,575	24,635	24,694	24,754	24,813	24,873	24,932
42	24,991.735	25,051	25,111	25,170	25,230	25,289	25,349	25,408	25,468	25,527
43	25,586.776	25,646	25,706	25,765	25,825	25,884	25,944	26,003	26,063	26,122
44	26,181.817	26,241	26,301	26,360	26,420	26,479	26,539	26,598	26,658	26,717
45	26,776.858	26,836	26,896	26,955	27,015	27,074	27,134	27,193	27,253	27,312
46	27,371.900	27,431	27,491	27,550	27,610	27,669	27,729	27,788	27,848	27,907
47	27,966.941	28,026	28,086	28,145	28,205	28,264	28,324	28,383	28,443	28,502
48	28,561.982	28,621	28,681	28,740	28,800	28,860	28,919	28,979	29,038	29,098
49	29,157.024	29,217	29,276	29,336	29,395	29,455	29,514	29,574	29,633	29,693

Discharge in second-feet into run-off in acre-feet per month of 30 days—Continued.

No.	0	1	2	3	4	5	6	7	8	9
50	29, 752. 065	29, 812	29, 871	29, 931	29, 990	30, 050	30, 109	30, 169	30, 228	30, 288
51	30, 347. 106	30, 407	30, 466	30, 526	30, 585	30, 645	30, 704	30, 764	30, 823	30, 883
52	30, 942. 148	31, 002	31, 061	31, 121	31, 180	31, 240	31, 299	31, 359	31, 418	31, 478
53	31, 537. 189	31, 597	31, 656	31, 716	31, 775	31, 835	31, 894	31, 954	32, 013	32, 073
54	32, 132. 230	32, 192	32, 251	32, 311	32, 370	32, 430	32, 489	32, 549	32, 608	32, 668
55	32, 727. 272	32, 787	32, 846	32, 906	32, 965	33, 025	33, 084	33, 144	33, 203	33, 263
56	33, 322. 313	33, 382	33, 441	33, 501	33, 560	33, 620	33, 679	33, 739	33, 798	33, 858
57	33, 917. 354	33, 977	34, 036	34, 096	34, 155	34, 215	34, 274	34, 334	34, 393	34, 453
58	34, 512. 395	34, 572	34, 631	34, 691	34, 750	34, 810	34, 869	34, 929	34, 988	35, 048
59	35, 107. 437	35, 167	35, 226	35, 286	35, 345	35, 405	35, 464	35, 524	35, 583	35, 643
60	35, 702. 478	35, 762	35, 821	35, 881	35, 940	36, 000	36, 060	36, 119	36, 179	36, 238
61	36, 297. 519	36, 357	36, 417	36, 476	36, 536	36, 595	36, 655	36, 714	36, 774	36, 833
62	36, 892. 561	36, 952	37, 012	37, 071	37, 131	37, 190	37, 250	37, 309	37, 369	37, 428
63	37, 487. 602	37, 547	37, 607	37, 666	37, 726	37, 785	37, 845	37, 904	37, 964	38, 023
64	38, 082. 643	38, 142	38, 202	38, 261	38, 321	38, 380	38, 440	38, 499	38, 559	38, 618
65	38, 677. 684	38, 737	38, 797	38, 856	38, 916	38, 975	39, 035	39, 094	39, 154	39, 213
66	39, 272. 726	39, 332	39, 392	39, 451	39, 511	39, 570	39, 630	39, 689	39, 749	39, 808
67	39, 867. 767	39, 927	39, 987	40, 046	40, 106	40, 165	40, 225	40, 284	40, 344	40, 403
68	40, 462. 808	40, 522	40, 582	40, 641	40, 701	40, 760	40, 820	40, 879	40, 939	40, 998
69	41, 057. 850	41, 117	41, 177	41, 236	41, 296	41, 355	41, 415	41, 474	41, 534	41, 593
70	41, 652. 891	41, 712	41, 772	41, 831	41, 891	41, 950	42, 010	42, 069	42, 129	42, 188
71	42, 247. 932	42, 307	42, 367	42, 426	42, 486	42, 545	42, 605	42, 664	42, 724	42, 783
72	42, 842. 974	42, 902	42, 962	43, 021	43, 081	43, 140	43, 200	43, 260	43, 319	43, 379
73	43, 438. 015	43, 498	43, 557	43, 617	43, 676	43, 736	43, 795	43, 855	43, 914	43, 974
74	44, 033. 056	44, 093	44, 152	44, 212	44, 271	44, 331	44, 390	44, 450	44, 509	44, 569
75	44, 628. 098	44, 688	44, 747	44, 807	44, 866	44, 926	44, 985	45, 045	45, 104	45, 164
76	45, 223. 139	45, 283	45, 342	45, 402	45, 461	45, 521	45, 580	45, 640	45, 699	45, 759
77	45, 818. 180	45, 878	45, 937	45, 997	46, 056	46, 116	46, 175	46, 235	46, 294	46, 354
78	46, 413. 221	46, 473	46, 532	46, 592	46, 651	46, 711	46, 770	46, 830	46, 889	46, 949
79	47, 008. 263	47, 068	47, 127	47, 187	47, 246	47, 306	47, 365	47, 425	47, 484	47, 544
80	47, 603. 304	47, 663	47, 722	47, 782	47, 841	47, 901	47, 960	48, 020	48, 079	48, 139
81	48, 198. 345	48, 258	48, 317	48, 377	48, 436	48, 496	48, 555	48, 615	48, 674	48, 734
82	48, 793. 387	48, 853	48, 912	48, 972	49, 031	49, 091	49, 150	49, 210	49, 269	49, 329
83	49, 388. 428	49, 448	49, 507	49, 567	49, 626	49, 686	49, 745	49, 805	49, 864	49, 924
84	49, 983. 469	50, 043	50, 102	50, 162	50, 221	50, 281	50, 340	50, 400	50, 460	50, 519
85	50, 578. 510	50, 638	50, 698	50, 757	50, 817	50, 876	50, 936	50, 995	51, 055	51, 114
86	51, 173. 552	51, 233	51, 293	51, 352	51, 412	51, 471	51, 531	51, 590	51, 650	51, 709
87	51, 768. 593	51, 828	51, 888	51, 947	52, 007	52, 066	52, 126	52, 185	52, 245	52, 304
88	52, 363. 634	52, 423	52, 483	52, 542	52, 602	52, 661	52, 721	52, 780	52, 840	52, 899
89	52, 958. 676	53, 018	53, 078	53, 137	53, 197	53, 256	53, 316	53, 375	53, 435	53, 494
90	53, 553. 717	53, 613	53, 673	53, 732	53, 792	53, 851	53, 911	53, 970	54, 030	54, 089
91	54, 148. 758	54, 208	54, 268	54, 327	54, 387	54, 446	54, 506	54, 565	54, 625	54, 684
92	54, 743. 800	54, 803	54, 863	54, 922	54, 982	55, 041	55, 101	55, 160	55, 220	55, 279
93	55, 338. 841	55, 398	55, 458	55, 517	55, 577	55, 636	55, 695	55, 755	55, 815	55, 874
94	55, 933. 882	55, 993	56, 053	56, 112	56, 172	56, 231	56, 291	56, 350	56, 410	56, 469
95	56, 528. 924	56, 588	56, 648	56, 707	56, 767	56, 826	56, 886	56, 945	57, 005	57, 064
96	57, 123. 965	57, 183	57, 243	57, 302	57, 362	57, 421	57, 481	57, 540	57, 600	57, 660
97	57, 719. 006	57, 779	57, 838	57, 898	57, 957	58, 017	58, 076	58, 136	58, 195	58, 255
98	58, 314. 047	58, 374	58, 433	58, 493	58, 552	58, 612	58, 671	58, 731	58, 790	58, 850
99	58, 909. 089	58, 969	59, 028	59, 088	59, 147	59, 207	59, 266	59, 326	59, 385	59, 445

Discharge in second-feet into run-off in acre-feet per month of 31 days.

No.	0	1	2	3	4	5	6	7	8	9
0	0.000	61	123	184	246	307	369	430	492	553
1	614.876	676	738	799	861	922	984	1,045	1,107	1,168
2	1,229.752	1,291	1,353	1,414	1,476	1,537	1,599	1,660	1,722	1,783
3	1,844.628	1,906	1,968	2,029	2,091	2,152	2,214	2,275	2,337	2,398
4	2,459.504	2,521	2,582	2,644	2,705	2,767	2,828	2,890	2,951	3,013
5	3,074.380	3,136	3,197	3,259	3,320	3,382	3,443	3,505	3,566	3,628
6	3,689.256	3,751	3,812	3,874	3,935	3,997	4,058	4,120	4,181	4,243
7	4,304.132	4,366	4,427	4,489	4,550	4,612	4,673	4,735	4,796	4,858
8	4,919.008	4,980	5,042	5,103	5,165	5,226	5,288	5,349	5,411	5,472
9	5,533.884	5,595	5,657	5,718	5,780	5,841	5,903	5,964	6,026	6,087
10	6,148.760	6,210	6,272	6,333	6,395	6,456	6,518	6,579	6,641	6,702
11	6,763.636	6,825	6,887	6,948	7,010	7,071	7,133	7,194	7,256	7,317
12	7,378.512	7,440	7,501	7,563	7,624	7,686	7,747	7,809	7,870	7,932
13	7,993.388	8,055	8,116	8,178	8,239	8,301	8,362	8,424	8,485	8,547
14	8,608.264	8,670	8,731	8,793	8,854	8,916	8,977	9,039	9,100	9,162
15	9,223.140	9,285	9,346	9,408	9,469	9,531	9,592	9,654	9,715	9,777
16	9,838.016	9,900	9,961	10,022	10,084	10,145	10,207	10,268	10,330	10,391
17	10,452.892	10,514	10,576	10,637	10,699	10,760	10,822	10,883	10,945	11,006
18	11,067.768	11,129	11,191	11,252	11,314	11,375	11,437	11,498	11,560	11,621
19	11,682.644	11,744	11,806	11,867	11,929	11,990	12,052	12,113	12,175	12,236
20	12,297.520	12,359	12,420	12,482	12,543	12,605	12,666	12,728	12,789	12,851
21	12,912.396	12,974	13,035	13,097	13,158	13,220	13,281	13,343	13,404	13,466
22	13,527.272	13,589	13,650	13,712	13,773	13,835	13,896	13,958	14,019	14,081
23	14,142.148	14,204	14,265	14,327	14,388	14,450	14,511	14,573	14,634	14,696
24	14,757.024	14,819	14,880	14,941	15,003	15,064	15,126	15,187	15,249	15,310
25	15,371.900	15,433	15,495	15,556	15,618	15,679	15,741	15,802	15,864	15,925
26	15,986.776	16,048	16,110	16,171	16,233	16,294	16,356	16,417	16,479	16,540
27	16,601.652	16,663	16,725	16,786	16,848	16,909	16,971	17,032	17,094	17,155
28	17,216.528	17,278	17,340	17,401	17,462	17,524	17,585	17,647	17,708	17,770
29	17,831.404	17,893	17,954	18,016	18,077	18,139	18,200	18,262	18,323	18,385
30	18,446.280	18,508	18,569	18,631	18,692	18,754	18,815	18,877	18,938	19,000
31	19,061.156	19,123	19,184	19,246	19,307	19,369	19,430	19,492	19,553	19,615
32	19,676.032	19,738	19,799	19,860	19,922	19,983	20,045	20,106	20,168	20,229
33	20,290.908	20,352	20,414	20,475	20,537	20,598	20,660	20,721	20,783	20,844
34	20,905.784	20,967	21,029	21,090	21,152	21,213	21,275	21,336	21,398	21,459
35	21,520.660	21,582	21,644	21,705	21,767	21,828	21,890	21,951	22,013	22,074
36	22,135.536	22,197	22,259	22,320	22,381	22,443	22,504	22,566	22,627	22,689
37	22,750.412	22,812	22,873	22,935	22,996	23,058	23,119	23,181	23,242	23,304
38	23,365.288	23,427	23,488	23,550	23,611	23,673	23,734	23,796	23,857	23,919
39	23,980.164	24,042	24,103	24,165	24,226	24,288	24,349	24,411	24,472	24,534
40	24,595.040	24,657	24,718	24,780	24,841	24,902	24,964	25,025	25,087	25,148
41	25,209.916	25,271	25,333	25,394	25,456	25,517	25,579	25,640	25,702	25,763
42	25,824.792	25,886	25,948	26,009	26,071	26,132	26,194	26,255	26,317	26,378
43	26,439.668	26,501	26,563	26,624	26,686	26,747	26,809	26,870	26,932	26,993
44	27,054.544	27,116	27,178	27,239	27,300	27,362	27,423	27,485	27,546	27,608
45	27,669.420	27,731	27,792	27,854	27,915	27,977	28,038	28,100	28,161	28,223
46	28,284.296	28,346	28,407	28,469	28,530	28,592	28,653	28,715	28,776	28,838
47	28,899.172	28,960	29,022	29,084	29,145	29,207	29,268	29,330	29,391	29,453
48	29,514.048	29,576	29,637	29,699	29,760	29,821	29,883	29,944	30,006	30,067
49	30,128.924	30,190	30,252	30,313	30,375	30,436	30,498	30,559	30,621	30,682

Discharge in second-feet into run-off in acre-feet per month of 31 days—Continued.

No.	0	1	2	3	4	5	6	7	8	9
50	30, 743. 800	30, 805	30, 867	30, 928	30, 990	31, 051	31, 113	31, 174	31, 236	31, 297
51	31, 358. 677	31, 420	31, 482	31, 543	31, 605	31, 666	31, 728	31, 789	31, 851	31, 912
52	31, 973. 553	32, 035	32, 097	32, 158	32, 220	32, 281	32, 342	32, 404	32, 465	32, 527
53	32, 588. 429	32, 650	32, 711	32, 773	32, 834	32, 896	32, 957	33, 019	33, 080	33, 142
54	33, 203. 305	33, 265	33, 326	33, 388	33, 449	33, 511	33, 572	33, 634	33, 695	33, 757
55	33, 818. 181	33, 880	33, 941	34, 003	34, 064	34, 126	34, 187	34, 249	34, 310	34, 372
56	34, 433. 057	34, 495	34, 556	34, 618	34, 679	34, 740	34, 802	34, 863	34, 925	34, 986
57	35, 047. 933	35, 109	35, 171	35, 232	35, 294	35, 355	35, 417	35, 478	35, 540	35, 601
58	35, 662. 809	35, 724	35, 786	35, 847	35, 909	35, 970	36, 032	36, 093	36, 155	36, 216
59	36, 277. 685	36, 339	36, 401	36, 462	36, 524	36, 585	36, 647	36, 708	36, 770	36, 831
60	36, 892. 561	36, 954	37, 016	37, 077	37, 139	37, 200	37, 261	37, 323	37, 384	37, 446
61	37, 507. 437	37, 569	37, 630	37, 692	37, 753	37, 815	37, 876	37, 938	37, 999	38, 061
62	38, 122. 313	38, 184	38, 245	38, 307	38, 368	38, 430	38, 491	38, 553	38, 614	38, 676
63	38, 737. 189	38, 799	38, 860	38, 922	38, 983	39, 045	39, 106	39, 168	39, 229	39, 291
64	39, 352. 065	39, 414	39, 475	39, 537	39, 598	39, 660	39, 721	39, 782	39, 844	39, 905
65	39, 966. 941	40, 028	40, 090	40, 151	40, 213	40, 274	40, 336	40, 397	40, 459	40, 520
66	40, 581. 817	40, 643	40, 705	40, 766	40, 828	40, 889	40, 951	41, 012	41, 074	41, 135
67	41, 196. 693	41, 258	41, 320	41, 381	41, 443	41, 504	41, 566	41, 627	41, 689	41, 750
68	41, 811. 569	41, 873	41, 935	41, 996	42, 058	42, 119	42, 180	42, 242	42, 303	42, 365
69	42, 426. 445	42, 488	42, 549	42, 611	42, 672	42, 734	42, 795	42, 857	42, 918	42, 980
70	43, 041. 321	43, 103	43, 164	43, 226	43, 287	43, 349	43, 410	43, 472	43, 533	43, 595
71	43, 656. 197	43, 718	43, 779	43, 841	43, 902	43, 964	44, 025	44, 087	44, 148	44, 210
72	44, 271. 073	44, 333	44, 394	44, 456	44, 517	44, 579	44, 640	44, 701	44, 763	44, 824
73	44, 885. 949	44, 947	45, 009	45, 070	45, 132	45, 193	45, 255	45, 316	45, 378	45, 439
74	45, 500. 825	45, 562	45, 624	45, 685	45, 747	45, 808	45, 870	45, 931	45, 993	46, 054
75	46, 115. 701	46, 177	46, 239	46, 300	46, 362	46, 423	46, 485	46, 546	46, 608	46, 669
76	46, 730. 577	46, 792	46, 854	46, 915	46, 977	47, 038	47, 100	47, 161	47, 222	47, 284
77	47, 345. 453	47, 407	47, 468	47, 530	47, 591	47, 653	47, 714	47, 776	47, 837	47, 899
78	47, 960. 329	48, 022	48, 083	48, 145	48, 206	48, 268	48, 329	48, 391	48, 452	48, 514
79	48, 575. 205	48, 637	48, 698	48, 760	48, 821	48, 883	48, 944	49, 006	49, 067	49, 129
80	49, 190. 081	49, 252	49, 313	49, 375	49, 436	49, 498	49, 559	49, 620	49, 682	49, 743
81	49, 804. 957	49, 866	49, 928	49, 989	50, 051	50, 112	50, 174	50, 235	50, 297	50, 358
82	50, 419. 833	50, 481	50, 543	50, 604	50, 666	50, 727	50, 789	50, 850	50, 912	50, 973
83	51, 034. 709	51, 096	51, 158	51, 219	51, 281	51, 342	51, 404	51, 465	51, 527	51, 588
84	51, 649. 585	51, 711	51, 773	51, 834	51, 896	51, 957	52, 019	52, 080	52, 141	52, 203
85	52, 264. 461	52, 326	52, 387	52, 449	52, 510	52, 572	52, 633	52, 695	52, 756	52, 818
86	52, 879. 337	52, 941	53, 002	53, 064	53, 125	53, 187	53, 248	53, 310	53, 371	53, 433
87	53, 494. 213	53, 556	53, 617	53, 679	53, 740	53, 802	53, 863	53, 925	53, 986	54, 048
88	54, 109. 089	54, 171	54, 232	54, 294	54, 355	54, 417	54, 478	54, 540	54, 601	54, 662
89	54, 723. 965	54, 785	54, 847	54, 908	54, 970	55, 031	55, 093	55, 154	55, 216	55, 277
90	55, 338. 841	55, 400	55, 462	55, 523	55, 585	55, 646	55, 708	55, 769	55, 831	55, 892
91	55, 953. 717	56, 015	56, 077	56, 138	56, 200	56, 261	56, 323	56, 384	56, 446	56, 507
92	56, 568. 593	56, 630	56, 692	56, 753	56, 815	56, 876	56, 938	56, 999	57, 060	57, 122
93	57, 183. 469	57, 245	57, 306	57, 368	57, 429	57, 491	57, 552	57, 614	57, 675	57, 737
94	57, 798. 345	57, 860	57, 921	57, 983	58, 044	58, 106	58, 167	58, 229	58, 290	58, 352
95	58, 413. 221	58, 475	58, 536	58, 598	58, 659	58, 721	58, 782	58, 844	58, 905	58, 967
96	59, 028. 097	59, 090	59, 151	59, 213	59, 274	59, 336	59, 397	59, 459	59, 520	59, 581
97	59, 642. 973	59, 704	59, 766	59, 827	59, 889	59, 950	60, 012	60, 073	60, 135	60, 196
98	60, 257. 849	60, 319	60, 381	60, 442	60, 504	60, 565	60, 627	60, 688	60, 750	60, 811
99	60, 872. 725	60, 934	60, 996	61, 057	61, 119	61, 180	61, 242	61, 303	61, 365	61, 426

Discharge in second-feet into theoretical horsepower per foot of fall.

[1 second-foot=0.1136 theoretical horsepower per foot of fall. Weight of 1 cubic foot of water=62.5 pounds.]

Tens.	Units.									
	0	1	2	3	4	5	6	7	8	9
0.....	0.00	0.114	0.227	0.341	0.454	0.568	0.682	0.795	0.909	1.02
1.....	1.14	1.25	1.36	1.48	1.59	1.70	1.82	1.93	2.04	2.16
2.....	2.27	2.39	2.50	2.61	2.73	2.84	2.95	3.07	3.18	3.29
3.....	3.41	3.52	3.64	3.75	3.86	3.98	4.09	4.20	4.32	4.43
4.....	4.54	4.66	4.77	4.88	5.00	5.11	5.23	5.34	5.45	5.57
5.....	5.68	5.79	5.91	6.02	6.13	6.25	6.36	6.48	6.59	6.70
6.....	6.82	6.93	7.04	7.16	7.27	7.38	7.50	7.61	7.72	7.84
7.....	7.95	8.07	8.18	8.29	8.41	8.52	8.63	8.75	8.86	8.97
8.....	9.09	9.20	9.32	9.43	9.54	9.66	9.77	9.88	10.0	10.1
9.....	10.2	10.3	10.5	10.6	10.7	10.8	10.9	11.0	11.1	11.2

CONVENIENT EQUIVALENTS.**LENGTH.**1 inch= $\frac{1}{36}$ foot=0.027778 yard=0.000015783 mile=2.54 centimeters.1 foot=12 inches= $\frac{1}{3}$ yard=0.00018939 mile=0.3048 meter.

1 yard=36 inches=3 feet=0.00056818 mile=0.9144 meter.

1 mile=63,360 inches=5,280 feet=1,760 yards=1.60935 kilometers.

1 meter=100 centimeters=0.001 kilometer=39.37 inches=3.2808 feet=1.0936 yards=0.00062137 mile.

SURFACE.

1 square inch=0.006944 square foot=0.0007716 square yard=0.0000001594 acre=0.0000000002491 square mile=6.45163 square centimeters.

1 square foot=144 square inches= $\frac{1}{9}$ square yard=0.000022957 acre=0.00000003587 square mile=0.092903 square meter.

1 square yard=1,296 square inches=9 square feet=0.0002066 acre=0.0000003228 square mile=0.83613 square meter.

1 acre=6,272,640 square inches=43,560 square feet=4,840 square yards=0.0015625 square mile=208.71 feet square=0.404687 hectare.

1 square mile=4,014,489,600 square inches=27,878,400 square feet=3,097,600 square yards=640 acres=259 hectares.

1 square meter=10,000 square centimeters=0.0001 hectare=0.000001 square kilometer=1,550 square inches=10.7639 square feet=1.19598 square yards=0.0002471 acre=0.0000003861 square mile.

VOLUME.

1 cubic inch=0.004329 United States gallon=0.0005787 cubic foot=16.3872 cubic centimeters.

1 United States gallon=231 cubic inches=0.13368 cubic foot=0.00000307 acre foot=3.78543 liters.

1 cubic foot=1,728 cubic inches=7.4805 United States gallons=0.037037 cubic yard=0.000022957 acre-foot=28.317 liters.

1 cubic yard=46,656 cubic inches=27 cubic feet=0.00061983 acre-foot=0.76456 cubic meter.

1 acre-foot=325,851 United States gallons=43,560 cubic feet=1,613 $\frac{1}{3}$ cubic yards=1,233.49 cubic meters.

1 cubic meter, stere, or kiloliter=1,000,000 cubic centimeters=1,000 liters=61,023.4 cubic inches=264.17 United States gallons=35.3145 cubic feet=1.30794 cubic yards=0.000810708 acre-foot.

HYDRAULICS.

- 1 United States gallon of water weighs 8.34 pounds avoirdupois.
 1 cubic foot of water weighs 62.5 pounds avoirdupois.
 1 second-foot=7.48 United States gallons per second=448.8 United States gallons per minute=26,929.9 United States gallons per hour=646,317 United States gallons per day.
 1 second-foot=60 cubic feet per minute=3,600 cubic feet per hour=86,400 cubic feet per day=31,536,000 cubic feet per year=0.000214 cubic miles per year.
 1 second-foot=0.9917 acre-inch per hour=1.983471 acre-feet per day=723.966942 acre-feet per year.
 1 second-foot=50 miner's inches in Idaho, Kansas, Nebraska, New Mexico, North Dakota, and South Dakota=40 miner's inches in Arizona, California, Montana, and Oregon=38.4 miner's inches in Colorado.
 1 second-foot=0.028317 cubic meter per second=1.699 cubic meters per minute=101.941 cubic meters per hour=2,446.58 cubic meters per day.
 1 cubic meter per minute=0.5886 second-foot=4.403 United States gallons per second=1.1674 acre-feet per day.
 1 million gallons per day=1.55 second-feet=3.07 acre-feet per day=2.629 cubic meters per minute.
 1 second-foot falling 8.81 feet=1 horsepower.
 1 second-foot falling 10 feet=1.135 horsepower.
 1 second-foot falling 11 feet=1 horsepower, 80 per cent efficiency.
 1 second-foot for 1 year (365 days) will cover 1 square mile 1.1312 feet or 13.5744 inches deep.
 1 inch deep on 1 square mile=2,323,200 cubic feet=0.0737 second-foot for 1 year.
 1,000,000,000 (1 United States billion) cubic feet=11,570 second-feet for one day=413 second-feet for one 28-day month=399 second-feet for one 29-day month=386 second-feet for one 30-day month=373 second-feet for one 31-day month.
 100 California miner's inches=18.7 United States gallons per second=4.96 acre-feet in one day.
 100 Colorado miner's inches=2.60 second-feet=19.5 United States gallons per second=5.17 acre-feet in one day.
 100 United States gallons per minute=0.223 second-foot=0.442 acre-foot in one day.
 1 foot deep (head of 1 foot)=0.434 pound pressure on 1 square inch.

MISCELLANEOUS.

- 1 foot per second=0.68 mile per hour=1.097 kilometers per hour.
 1 avoirdupois pound=7,000 grains=0.4536 kilogram.
 1 kilogram=1,000 grams=0.001 tonne=15,432 grains=2.2046 pounds avoirdupois.
 1 atmosphere=about 15 pounds per square inch, about 1 ton per square foot, and about 1 kilogram per square centimeter.
 Acceleration of gravity, g ,=32.16 feet per second.
 1 mil=0.001 inch.
 1 circular mil= $\frac{\pi}{4}$ (0.001)² or 0.0000007854 square inch.
 1 square inch=1,273,240 circular mils.
 No. 10 Birmingham gage wire has a diameter of 134 mils and a cross-sectional area of 14,103 circular mils.
 1 horsepower=5,694,120 foot-gallons per day=550 foot-pounds per second=33,000 foot-pounds per minute=1,980,000 foot-pounds per hour=2,545 British thermal units per hour=76 kilogrammeters per second=1.27 kilogrammeters per minute=746 watts.
 74351°—19—WSP 425—7

1 horsepower, boiler rating, requires the evaporation of $34\frac{1}{2}$ pounds per hour of water at 212° F. to dry steam at the same temperature; or the expenditure of 33,317 British thermal units; and in practice is developed by burning $3\frac{1}{2}$ to $4\frac{1}{2}$ pounds per hour of coal under 10 to 12 square feet of heating surface.

1 British thermal unit=778 foot-pounds.

1 pound of bituminous coal contains about 14,100 British thermal units, or 11,000,000 foot-pounds of energy.

Best engine efficiency is about 18 per cent and requires 1 pound of coal per hour per horsepower. Average efficiency is about 10 per cent and requires 1.8 pounds of coal per hour per horsepower.

MAP SCALES.

	Inches to 1 mile.	Miles to 1 inch.		Inches to 1 mile.	Miles to 1 inch.
1:1,000,000=	0.06336=	15.78282	1:63,360=	1.00000=	1.00000
1:500,000 =	.12672=	7.89141	1:62,500=	1.01376=	.98642
1:250,000 =	.25344=	3.94570	1:45,000=	1.40800=	.71023
1:126,720 =	.50000=	2.00000	1:31,680=	2.00000=	.50000
1:125,000 =	.50688=	1.97285	1:30,000=	2.11200=	.47349
1:90,000 =	.70400=	1.42046	1:24,000=	2.64000=	.378787

GROUND WATER IN REESE RIVER BASIN AND ADJACENT PARTS OF HUMBOLDT RIVER BASIN, NEVADA.

By **GERALD A. WARING.**

INTRODUCTION.

GROUND WATER FOR IRRIGATION IN NEVADA.

One of the remarkable achievements in the winning of the West has been the development of great areas of tillable land into a multitude of farms within the last half century. In the last decade, however, Government land that is suitable for farming and open to entry has become scarce because of the rapid homesteading in the desirable areas. The realization by prospective homesteaders that lands suitable for farming are becoming scarce has apparently served as a stimulus to settlement, and many entries have been made on lands that are unsuitable for farming.

In Nevada the mountains lie in approximately parallel ranges that trend in general nearly north, and the valleys between them are deeply underlain by gravel, sand, and clay, brought down by flood water from the bordering mountain slopes. This unconsolidated valley fill serves as a great reservoir in which much of the water that falls as rain or snow becomes stored as ground water, and in some valleys in Nevada this water is available for irrigation by means of wells and pumping plants.

At some places, however, the ground water is too alkaline for successful use in irrigation, or it lies at a depth so great that the cost of pumping would be excessive, or it can not be developed in amount sufficient to make its use economically successful. It is therefore important that the ground-water conditions be carefully studied before agricultural settlement is attempted.

INVESTIGATION OF GROUND WATER IN REESE RIVER BASIN.

As a continuation of the United States Geological Survey's studies of ground water in Nevada the writer was assigned to make an examination of the drainage basin of Reese River and adjacent parts of the basin of Humboldt River, in the central part of the State (see Pl. VII), and spent the month of September, 1916, in this study, in company with Ernest L. Neill, of Stanford University. Acknowledgment is due to Mr. Neill for able assistance rendered and to many ranchmen for hospitality and for information furnished.

GEOGRAPHY OF THE AREA.

Reese River flows in a nearly direct course a little east of north from its headwaters in the Toyabe Range to its junction with Humboldt River. It is about 150 miles long, and its drainage basin is 12 to 30 miles wide. The valley occupies, at most places along its course, hardly one-third of the width of the drainage basin, and in its middle part it is constricted to form the Reese River canyon. (See Pl. VIII, in pocket.) Antelope Valley and Buffalo Valley are connected with the valley of Reese River by broad lowlands. In each of these tributary valleys the storm waters gather in a playa which is dry most of the year but in wet seasons forms a lake or expanse of alkali-incrusted mud. These playas rarely overflow to Reese River.

From an elevation of about 7,400 feet in Indian Valley, at the south end of the basin, the valley descends at a fairly uniform grade northward along Reese River to an elevation of only 4,500 feet at the junction of Reese River with the Humboldt. The principal peaks in the mountains that border the northern and central parts of the basin are 7,000 to 9,000 feet above sea level. To the south the crest of the Toyabe Range is for the most part more than 10,000 feet above the sea, and Arc Dome, the culminating point of the range and of the rim of the drainage basin, has an elevation of 11,775 feet.

The climate of the area is arid. The average annual precipitation at Battle Mountain is about 7 inches; at Austin it is about 12½ inches, and in the higher mountains it may reach 20 inches. About half the precipitation falls in December to March, inclusive. July is usually the driest month of the year. In the mountains the precipitation is mainly in the form of snow; in the valleys the irregular summer rains usually come as thunderstorms.

Because of the dryness of the air and the relatively great elevation of the region above sea level, the daily range in temperature is great. It is said that in the southern part of the Reese River valley frosts may occur in any month of the year. The mean annual temperature is about 50° F.

The area is sparsely populated. In 1910, according to the census, Austin had a population of 700 and Battle Mountain 475. These are the only two towns in the area examined.

Austin (see Pl. IX, A) was formerly an important mining town, and soon after silver was discovered there, in May, 1862, it contained several thousand people. Of late years, since the principal mines were closed, it has served chiefly as a supply point for prospectors and ranchers and, as it is on the Lincoln Highway, for automobilists. It is connected with the Southern Pacific Railroad at Battle Mountain by the Nevada Central Railroad, a narrow-gage line 103 miles long.



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Battle Mountain is a shipping point for live stock and a supply and shipping point for mining interests. In 1916 there were small settlements at the mining camps of Galena and Copper Canyon, to the southwest, and at Lewis, Dean, Maysville, and Hilltop, to the southeast. The remainder of the inhabitants of this area live chiefly on the scattered ranches in the valley. These ranches are devoted to the raising of live stock, principally cattle. Native hay is extensively grown for winter feeding, and alfalfa also is raised on several ranches.

PHYSIOGRAPHY.

MOUNTAINS.

The southern part of the Reese River valley is bordered on the east by the Toyabe Range and on the west by the Shoshone Range. The river crosses to the west side of the Shoshone Range through Reese River canyon and thence flows northward. North of the canyon the east side of the river basin is formed by the Shoshone Range and the west side of the basin is bordered by parts of several ranges—the Desatoya Mountains at the south end of Antelope Valley, the Augusta Mountains on its west side, the Fish Creek Mountains along its north end, and the Havallah Range along the west side of Buffalo Valley. Battle Mountain forms a detached mass at the north end of Buffalo Valley.

The Toyabe Range is the highest of these ranges, containing peaks that rise more than 4,000 feet above the valley. The range as a whole is narrow and has a short, steep eastern front and longer, less precipitous western slopes. This form seems to have been produced by faulting and uplift along the east side of the range. Although this range is narrow and its slopes are in general steep, prolonged erosion prior to the uplift that gave it its present form produced undulating valleys and smoothed and rounded the summits in its higher parts.¹ These upland valleys form small areas of grazing land, where the grass keeps green well into the summer. Indian Valley (see Pl. X, B) probably acquired approximately its present form during this early erosional period. The most prominent rounded summit of the range is Mount Callahan, or "The Dome." From Reese River valley the Toyabe Range rises in a long, gentle slope that extends to its very top, but on its east side the slope is precipitous.

The Shoshone Range (called the Reese River Range by Spurr²) seems to be essentially anticlinal in structure, though its steepest fronts, notably those near Smith Canyon, have probably been produced by faulting. The hot springs in the lowlands a few miles south-

¹ Meinzer, O. E., *Geology and water resources of Big Smoky, Clayton, and Alkali Spring valleys, Nev.*: U. S. Geol. Survey Water-Supply Paper 423, pp. 18-22, 1917.

² Spurr, J. E., *Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California*: U. S. Geol. Survey Bull. 208, p. 97, 1903.

west of this canyon are presumably supplied by deep-seated water that rises along fault lines. The range seems to have been uplifted since the Reese River drainage system was established, and the stream has apparently maintained its course by cutting down through the rocks as fast as they were uplifted, in a way similar to that in which Yakima River in central Washington¹ and other rivers have cut gorges across lava ridges. Throughout the canyon the alluvium is several feet deep. Cutting apparently has ceased, and some filling of the canyon has taken place. Similar filling is well shown by Boone Creek. (See Pl. XI, *A*.)

The mountains and ranges along the west side of the northern half of the Reese River basin seem to be in general anticlinal in structure, though detailed study would probably show considerable faulting. Battle Mountain forms a detached mass whose sedimentary strata dip in the main westward, and early studies indicated that this mass may be an extension of the anticline of the Shoshone Range.²

ALLUVIAL FANS.

Extensive alluvial fans have been built out from the mouths of the numerous canyons on each side of the valley, and the larger of these fans continue, well defined but with gentler slopes, down to the lowlands along the river. The alluvial fan near the mouth of Big Creek (see Pl. X, *A*) is especially prominent, though it has been deeply dissected by the creek.

BLUFFS.

Unconsolidated sedimentary beds are exposed for considerable distances along the borders of the lower lands, and in several places they form prominent bluffs. The bluffs along the valley near Boone Creek (see Pl. IX, *B*) are carved in such materials. There are similar bluffs on the west side of the valley, opposite Austin, and also 40 miles farther south, on the east side of the valley, near the Schmalzing ranch.

PLAYAS.

The principal playas ("dry lakes" or alkali flats) in the drainage basin of Reese River are in Antelope and Buffalo valleys. The one in Antelope Valley has an area of only about 1 square mile, and it has an overflow channel that runs northward and eastward to Reese River. The one in Buffalo Valley is nearly 5 miles long from northeast to southwest and about 2 miles wide. During exceptionally wet seasons it may discharge northeastward to Reese River, but no outlet channel was noticed.

¹ Smith, G. O., U. S. Geol. Survey Geol. Atlas, Ellensburg folio (No. 86), p. 5, 1903.

² Hague, Arnold, and Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 667, 1877.

Along the lower course of Reese River there are extensive areas of poorly drained alkali land from which the spring flood water evidently runs off very slowly, but no depressions were observed where intermittent lakes may form.

GEOLOGY.

GEOLOGIC SKETCH.

The geologic history of the Reese River region is believed to be in brief as follows:¹

During Paleozoic and Mesozoic time the greater part of the region was submerged, and extensive deposits of limestone, sandstone, and shale were formed. The Reese River basin is geographically in a transition zone between the higher plateau lands of eastern Nevada and the lower lands farther west. Geologically, also, the basin is in a transition zone, for all the ancient sedimentary rocks along its east side are of Paleozoic age, whereas those on the west are of Mesozoic age.²

The evidence indicates that during the Paleozoic era an extensive area east of the Reese River basin was submerged, whereas the land for many miles westward stood above sea level. With the ending of the Paleozoic and the beginning of the Mesozoic era the conditions were reversed, the western region being submerged and the eastern region uplifted. Since the Mesozoic era central Nevada as a whole has been uplifted several thousand feet above sea level by widespread structural movement, and the present mountain ranges have been developed by both transverse and longitudinal stresses.³

The sedimentary rocks in the ranges bordering the Reese River valley have been intruded by granitoid rocks, which constitute the cores of the mountains.

During the Tertiary period large areas, including perhaps the greater part of the basin of Reese River, were occupied by extensive fresh-water lakes, in which beds of gravel, sand, and clay were deposited, together with layers of volcanic ash. After this lake period, probably in the Miocene epoch of the Tertiary, great floods of lava were poured out through numerous fissures or other centers of extrusion in the mountain ranges and buried deeply a large part of the Paleozoic and Mesozoic sedimentary rocks, as well as the Tertiary lake deposits. After this period of extrusive activity the region was much disturbed by crustal movements, and the principal mountain ranges, which were originally in the main anticlinal,

¹ For detailed discussions of the rocks and the geologic structure, see Hague, Arnold, and Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 615-683, 1877. For description of the mining districts see Hill, J. M., Some mining districts in northeastern California and northwestern Nevada: U. S. Geol. Survey Bull. 594, pp. 64-125, 1915.

² King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 412, 1878.

³ King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vol. 3, p. 325, 1870.

were profoundly faulted and tilted, so that their structure is now complex.

More recently the mountains have been extensively eroded, and the rock waste has been deposited in the lower parts of the basin. Reese River has cut its canyon across the Shoshone Range since the lavas were poured out, presumably in large part during Pliocene and Pleistocene time. During the Pleistocene epoch a perennial lake is believed to have occupied Buffalo Valley.¹

PALEOZOIC SEDIMENTARY ROCKS.

The Paleozoic sedimentary rocks consist of limestone, slate, and quartzite and were probably laid down throughout the Paleozoic era. They are exposed over extensive areas in the Toyabe and Shoshone ranges and in Battle Mountain (see Pl. VIII, in pocket) but not west of these ranges. The change in conditions of deposition (see p. 99) apparently accounts for the absence of Paleozoic sediments from the region west of Battle Mountain and the Shoshone Range.

MESOZOIC SEDIMENTARY ROCKS.

Limestone, shale, and sandstone that contain Mesozoic fossils form the Havallah Range along the west side of Buffalo Valley. Small exposures along the flanks of the Fish Creek, Augusta, and Desatoya mountains indicate that the Mesozoic rocks also compose the mass of these mountains beneath the thick sheets of lava that lie at the surface.

PRE-TERTIARY CRYSTALLINE ROCKS.

Areas of crystalline rocks, chiefly granitoid, are exposed along the crest of the Toyabe Range in the vicinity of Austin and near Mount Beseler, 40 miles to the south. Granite and diorite form the summit of Ravenswood Peak, in the Shoshone Range, and the crest of the range for about 10 miles south of this peak is formed of granite bordered by a narrow zone of crystalline schist. In the northern part of the range Shoshone Peak and adjacent areas are composed of granodiorite and other granular rocks.²

Along the west side of the basin granitoid rocks make up the north end of the Havallah Range; and exposures beyond the Reese River basin, along the flanks of the Fish Creek and Augusta mountains, indicate that the cores of these ranges also are composed of granitoid material. Small areas of diorite were mapped by the Fortieth Parallel Survey on the east slope of New Pass Mountain and in the Havallah Range.³

¹ See U. S. Geol. Expl. 40th Par. Atlas, map 5, 1876.

² Emmons, W. H., A reconnaissance of some mining camps in Elko, Lander, and Eureka counties, Nev.: U. S. Geol. Survey Bull. 408, pl. 5, 1910.

³ U. S. Geol. Expl. 40th Par. Atlas, map 5, 1876.

The ancient crystalline rocks of the Toyabe Range are intrusive in the Paleozoic rocks and are regarded by Hill¹ as of late Cretaceous or possibly of early Tertiary age. With the exception of the schists south of Ravenswood Peak that have been classed as Archean,² the crystalline rocks of the Shoshone and Havallah ranges are probably also intrusive in the Paleozoic and Mesozoic sedimentary rocks.

TERTIARY LAKE BEDS.

Around the border of Antelope Valley and in the Reese River valley upstream from the Reese River canyon the Tertiary lake beds are exposed at many places beneath the lava (see Pl. XII, *A* and *B*) or the overlying alluvium. These beds were early classed as Miocene and named the Truckee group.³

In Antelope Valley and in the vicinity of Italian and Silver creeks and the Reese River canyon the beds are composed chiefly of sand and clay but include considerable volcanic ash. Associated with the unconsolidated materials west of Austin there are beds of hard calcareous sandstone, which were also referred to the Truckee by the geologists of the Fortieth Parallel Survey. South of the area examined by these geologists there are prominent bluffs of light-colored sediments. In the vicinity of Schmalings's ranch (see Pl. VIII, in pocket) and near Warner's ranch there are deposits of coarse gravel consisting chiefly of well-rounded fragments of lava. These deposits have been shown on Plate VIII as belonging to the Truckee formation, but they may prove on detailed study not to be of this formation.

TERTIARY LAVAS.

The lavas of the Reese River basin are chiefly rhyolites, but small areas of andesites, trachytes, and basalts were mapped by the Fortieth Parallel Survey.⁴ The basaltic rocks seem to be the most recent in age. On the east side of Buffalo Valley there are two well-formed volcanic cones built up chiefly of trachyte, but the last material ejected from their craters is basaltic. In the Humboldt Basin, on the east border of Shoshone Mesa 1 or 2 miles south of the canyon of Rock Creek, basalt has been poured out over rhyolite, which is the prevailing rock, and the black color of the later flows contrasts with the prevailing red and brown tones of the earlier rock.

¹ Hill, J. M., Some mining districts in northeastern California and northwestern Nevada: U. S. Geol. Survey Bull. 594, p. 99, 1915. S. F. Emmons (U. S. Geol. Expl. 40th Par. Rept., vol. 3, p. 324, 1870) considered these rocks to be intrusive and hence of later age than the Paleozoic sediments; but King (idem, vol. 1, p. 75, 1878) seems to have believed them to be Archean and hence to underlie the Paleozoic deposits.

² Hague, Arnold, and Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 636, 1877.

³ King, Clarence, U. S. Expl. 40th Par. Rept., vol. 1, p. 414, 1878. Emmons, S. F., idem, vol. 2, p. 632, 1877.

⁴ U. S. Geol. Expl. 40th Par. Atlas, maps 4 and 5, 1876.

QUATERNARY DEPOSITS.

The lands in the valleys of Reese and Humboldt rivers are underlain by deposits of alluvium which drilled wells have penetrated for depths of several hundred feet without reaching solid rock. In Buffalo Valley the geologists of the Fortieth Parallel Survey distinguished the finer-grained deposits of the playa, which they called "Lower Quaternary" from the prevailingly more sandy deposits in the rest of the basin, which they called "Upper Quaternary," but these deposits are now known to be of approximately the same age.

Records of drilled wells indicate that throughout the Reese River basin the deposits in the lower lands are clayey rather than sandy. The extensive alluvial fans and slopes that border the lowlands contain much gravel and angular fragmental material, but the valley fill seems to be in large part fine grained and derived from the lake beds composing the Truckee formation. On the west side of the valley, opposite Austin, the Lincoln Highway crosses Quaternary deposits derived from the Truckee beds. In the fall of 1916 the road had become greatly cut up by automobile traffic, which rapidly wore deep ruts into the flourlike material.

PRECIPITATION.

Records of precipitation have been kept by the United States Weather Bureau at Austin (elevation 6,600 feet above sea level) and at Battle Mountain (elevation 4,500 feet). Although the records are not complete for every year since the beginning of observations, a

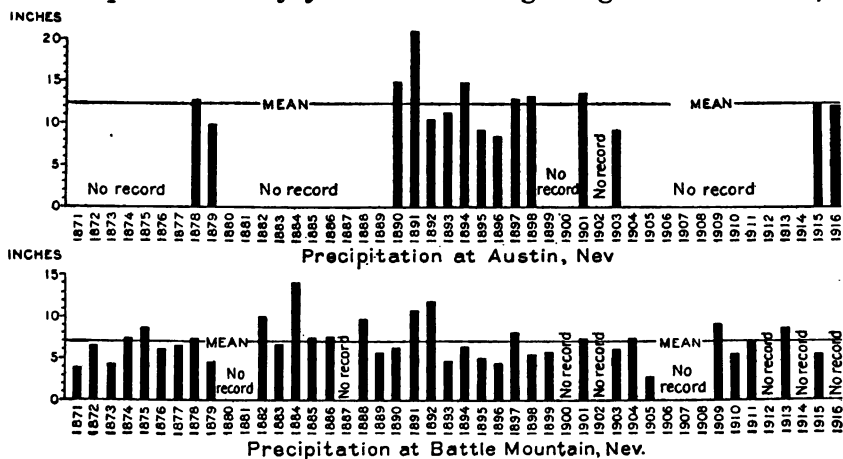
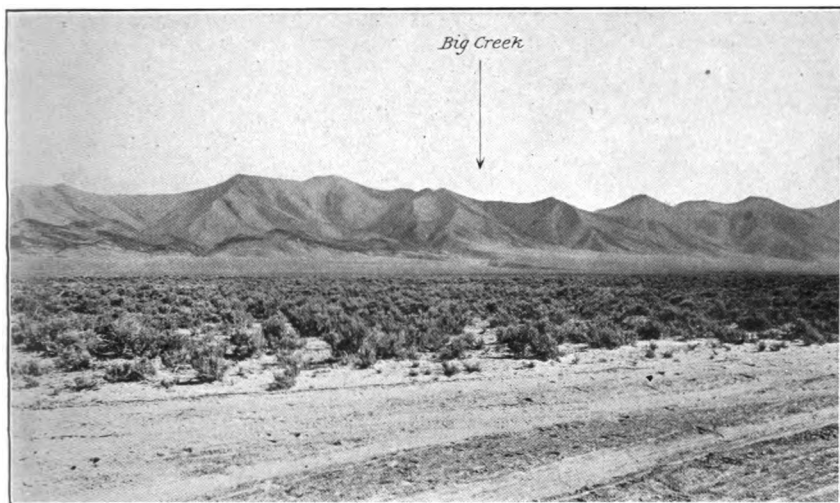
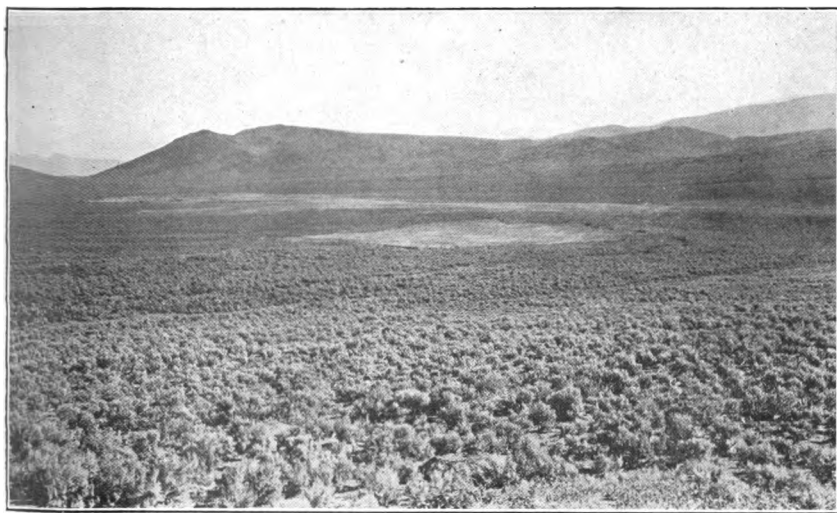


FIGURE 4.—Diagram showing annual precipitation at Austin and Battle Mountain, Nev.

sufficient number of records are available to show that the mean annual precipitation is about 12½ inches at Austin and 7 inches at Battle Mountain. The monthly and annual records are given in the following tables, and the annual totals are shown graphically in figure 4.



4. ALLUVIAL SLOPES NEAR MOUTH OF BIG CREEK, LOOKING SOUTHEASTWARD.



B. INDIAN VALLEY, LOOKING NORTHWARD FROM ITS HEAD.

GROUND WATER IN REESE AND HUMBOLDT RIVER BASINS, NEV. 103

Precipitation, in inches, at Austin, Nev., 1878-1916.^a

[No records for 1881-1887, 1899, 1909, 1910.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1878.	0.51	1.49	2.08	1.37	1.56	1.52	0.15	1.31	0.85	0.82	0.99	0.12	12.77
1879.	2.13	.58	.43	1.45	.46	1.15	.02	Tr.	Tr.	.85	.85	1.88	9.80
1880.	.34	1.25	1.08	2.92	.56	.01	.11	.11	.20				
1888.		.30		.25		Tr.	.09		1.00			.60	
1889.	.60				.25		0					.54	2.66
1890.	3.64	1.82	2.98	1.26	1.48	.05	.30	1.16	.45	.61	.10	1.10	14.95
1891.	.45	1.77	2.01	2.31	3.81	2.64	1.26	1.09	.85	.34	.23	4.31	21.07
1892.	.63	.56	1.72	1.34	1.90	1.47	.07	Tr.	.18	.24	.40	1.92	10.43
1893.	1.22	1.39	1.72	2.86	.88	0	1.02	.60	.32	.07	.55		11.22
1894.	1.39	1.89	1.63	1.82	.85	2.44	1.27	.50	.33	0	Tr.	2.77	14.89
1895.	1.43	1.29	.49	.61	2.66	.05	Tr.	.14	Tr.	.51	1.04	1.00	9.22
1896.	1.39	.05	1.30	1.41	1.76	.13	.85	.58	.39	0	.41	.18	8.45
1897.	1.30	2.11	1.79	.94	.61	.79	.39	.38	.07	2.76	.55	1.20	12.89
1898.	1.60	.27	1.43	1.16	4.18	.05	.40	.66	.30	.24	1.88	1.14	13.21
1900.				2.09	1.20	.63	.79	Tr.	.15	1.03	.86	.09	
1901.	1.24	4.14	.49	.15	2.02	.06	.51	1.84	.22	1.79	.88	.40	13.73
1902.	.43	1.10	1.51	1.18	.98	0	.48	.32	.34		1.26	.39	
1903.	1.80	.49	2.40	1.91	1.57	.60	0	.30	Tr.	0	.04	.13	9.24
1904.	1.01	2.22	.88	1.98	1.21	.06	.31	1.13	3.03		Tr.	.88	
1905.	.70		1.51	.91	.99	.03	.03					.73	
1906.	.31			2.56	2.50	1.28	.23	.97	.60	.30	1.41	1.83	
1907.	1.74							.02	.91	.36	1.00	2.62	
1908.	1.55	1.30	1.55	1.03	1.41								
1911.	1.30	2.70	1.50	.26	1.12	.01		.05	0		.12	.84	
1912.	.50		2.00					.65		1.60	.40	.60	
1913.	.95	.15	.97	2.00		2.86	1.60	2.70	.48	.30			
1914.								.13	.29	.56	0	.21	
1915.	1.26	.74	.94	4.54	2.21	0	.14	.41	.81	.02	.01	1.31	12.39
1916.	2.63	.96	1.48	.72	.22	0	.01	Tr.	1.28	3.39	.80	.50	11.90
Mean of the 15 complete records													12.41

^a U. S. Weather Bur. Bull. W, section 12, p. 2.*Precipitation, in inches, at Battle Mountain, Nev., 1870-1916.^a*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1870.				0.05	0.30	0.77	0	0	0	0.30	0.59	0.13	
1871.	0.12	0.22	0.37	.38	.65	.04	.47	0	0	.41	.26	.95	3.87
1872.	0	.20	.43	1.00	1.19	1.00	.50	0	1.31	.01	.02	.83	6.49
1873.	.10	2.10	.19	.05	.49	0	0	.02	.04	.05	.07	1.20	4.31
1874.	.95	1.56	1.07	.21	.40	0	.25	.80	0	1.38	.65	.15	7.42
1875.	2.57	.25	.60	.05	.90	0	0	.10	.06	.75	2.45	.93	8.66
1876.	.40	.30	1.05	.75	.24	.27	.53	0	.60	.53	1.21	.12	6.00
1877.	2.20	.53	2.07	.30	1.04	0	.20	0	0	.03	.40	0	6.77
1878.	.29	1.02	.44	.64	2.17	1.24	0	.90	.15	.31	.23	0	7.39
1879.	.65	.25	.16	.63	.45	.82	0	0	.08	.15	.46	.85	4.50
1880.	.08	.90		.59	.35	0	Tr.	0	0	0	Tr.	2.07	
1881.	1.23	.76	.45	.86		.28	0	.15	.16	.60	.58	1.03	
1882.	1.58	.70	2.10	1.27	.55	.83	.08	0	1.33	1.08	.15	.30	9.97
1883.	.86	.70	.60	1.12	1.27	.23	Tr.	0	0	.85	.70	.42	6.75
1884.	.70	2.30	1.04	1.54	1.29	2.18	0	.10	1.12	1.94	0	1.82	14.03
1885.	.55	1.48	.16	2.20	.61	.44	0	.33	0	0	.72	.91	7.40
1886.	1.30	.10	.27	1.72	.24	.21	.38	0	.18	1.20	1.50	.44	7.54
1887.	.73	1.15	.30	1.24	.14	.50	.12	.18		0	1.10	1.50	
1888.	3.12	.30	.25	.35	1.50	.51	.22	0	.65	.18	.82	1.89	9.79
1889.	.60	0	1.16	.45	.64	.23	0	0	0	1.55	0	1.04	5.67
1890.	2.55	.50	.81	.95	.25	0	0	.90	0	0	0	.30	6.26
1891.	.10	.75	.50	1.60	1.93	1.87	.17	0	0	.10	.25	3.52	10.79
1892.	.32	.58	2.18	2.55	2.35	1.82	0	0	.11	.35	.68	.83	11.77
1893.	1.42	.10	.73	1.18	.12	.10	.30	0	.25	.05	.25	.10	4.60
1894.	.38	1.25	.28	.40	1.25	1.15	.50	0	.10	Tr.	0	1.15	6.46
1895.	.95	1.65	.10	.30	.50	0	.15	0	.10	0	.37	.92	5.04
1896.	.60	.10	.85	.55	.90	0	0	0	.18	.85	.20	4.23	
1897.	.69	1.66	.54	.36	.35	1.22	0	0	1.90	.45	.91	8.08	
1898.	.47	.06	.55	.26	2.93	0	0	0	.50	.10	.32	.27	5.46
1899.	Tr.	Tr.	2.23	.20	.50	1.25	Tr.	.81	0	Tr.	0	.75	5.74
1900.	Tr.	.20	.10		.64		0	0	0			0	
1901.	.70	3.70	0	.86	0	0	0	.13	.68	.25	.45	.60	7.37

^a U. S. Weather Bur. Bull. W, section 12, pp. 2-3

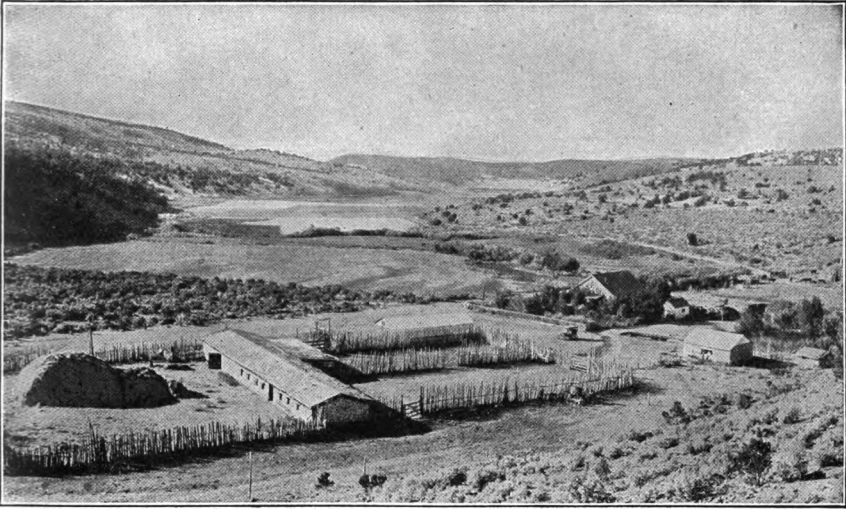
Precipitation, in inches, at Battle Mountain, Nev., 1870-1916^a—Continued.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1902.....	0.40	0.68	0.85	.....	0.25	0	0.80	0.10	0.19	0.10	0.70	0	.....
1903.....	1.35	.20	.92	0.30	.40	.34	0	0	0	.60	.90	1.10	6.11
1904.....	1.10	1.72	.60	.50	.75	Tr.	Tr.	Tr.	1.17	1.55	Tr.	Tr.	7.39
1905.....	Tr.	.40	.28	Tr.	.12	Tr.	0	.15	.10	.05	1.00	.70	2.80
1906.....	.90	.....	.....	.....	.....	.45	0	Tr.	0	Tr.	.50	.....	.....
1907.....	.....	.03	.61	.....	Tr.	Tr.	.....	.05	1.50	1.00	0	2.05	.....
1908.....	.47	.90	0.04	1.75	.83	.....	.09	0	1.00	.....	Tr.	0	.....
1909.....	2.40	.67	1.10	.14	Tr.	Tr.	Tr.	.75	.07	.20	2.98	.53	9.12
1910.....	1.60	.70	.08	.30	0	0	.51	0	.39	.31	.38	1.23	5.48
1911.....	1.47	.40	.32	1.40	1.20	.46	.47	0	.10	.10	.20	.80	6.92
1912.....	.20	.20	1.00	2.90	.20	.....	.15	.20	.20	1.11	.08	.30	.....
1913.....	.27	.05	.38	.56	.41	2.53	1.64	.37	.67	Tr.	.90	.78	8.56
1914.....	.55	.25	.....	.....	Tr.	.25	.10	0	.15	1.49	Tr.	.....	.....
1915.....	.30	.67	.20	2.40	1.51	0	.02	Tr.	Tr.	Tr.	.10	.02	5.22
1916.....	1.40	.72	.52	Tr.	Tr.	0	0	0	.....	.....	.....	.....	.....
Mean of the 35 complete records.....													6.97

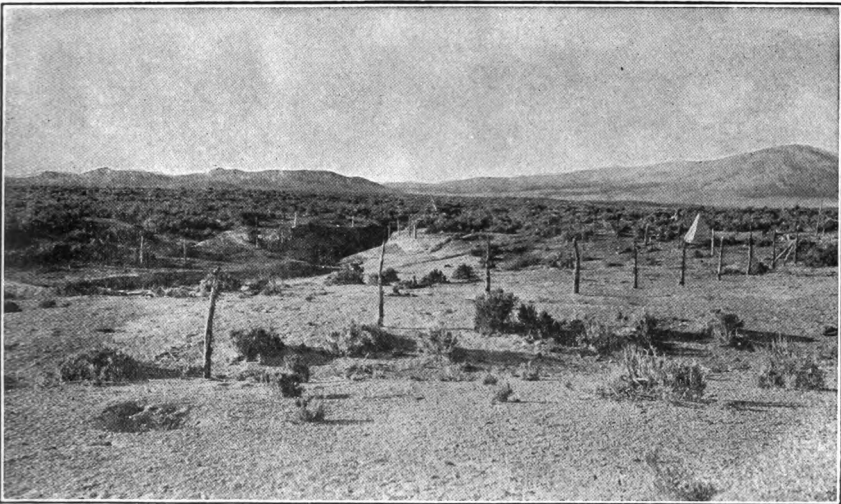
^a U. S. Weather Bur. Bull. W, section 12, pp. 2-3.^b Interpolated.**SURFACE WATER.**

Reese River is supplied chiefly by its headwaters in the upper slopes of the Toyabe Range. It has no large tributaries, and most of the creeks that drain its narrow basin sides are dry during the summer. Like many other streams of the arid regions, the river itself alternately rises and sinks during the dry season. Near its headwaters the river is perennial; but not far below the point where it enters the valley the water is diverted into several irrigation ditches, and its channel becomes dry during most summers for a stretch of 6 or 7 miles between the Derringer and Bowler ranches. A short distance above the Bowler ranch the water reappears in small amount, and downstream it gradually increases in volume. The reappearing underflow is considerably augmented by water from a group of springs at the Whaley ranch. The flow is again diverted and used in irrigation on the Walsh Hess ranch, and below the alfalfa fields and native hay meadows of this ranch the channel is usually dry for about 10 miles, to the vicinity of the Gondolfo ranch. There the underflow reappears in several groups of springs and is in part again diverted for irrigation, but most of it is allowed to sink in the river channel, and during the later part of summer the water seldom flows as far north as Boone Creek. The river channel from Boone Creek to Humboldt River is dry throughout the summer.

A record of the flow of Reese River has been obtained by the United States Geological Survey at a gaging station on the upper course of the river about $1\frac{1}{2}$ miles below Archie Bell's ranch and about 7 miles east of Berlin. The gage is a vertical staff on the left bank in the SW. $\frac{1}{4}$ sec. 16, T. 12 N., R. 40 E., about 75 yards above Illinois Creek and 100 yards above the headgate of the upper Bell



A. VALLEY OF BOONE CREEK, LOOKING DOWNSTREAM FROM MRS. LITSTER'S RANCH.



B. SPRING $1\frac{1}{2}$ MILES SOUTHWEST OF ANTELOPE SPRING, IN ANTELOPE VALLEY.

ditch. The drainage area is 94 square miles. The observer is Roy Bell. The daily and monthly discharge from June 10, 1913, to September 30, 1916, are given in the following tables:

Daily discharge, in second-feet, of Reese River above Illinois Creek for the years ending Sept. 30, 1913-1916.

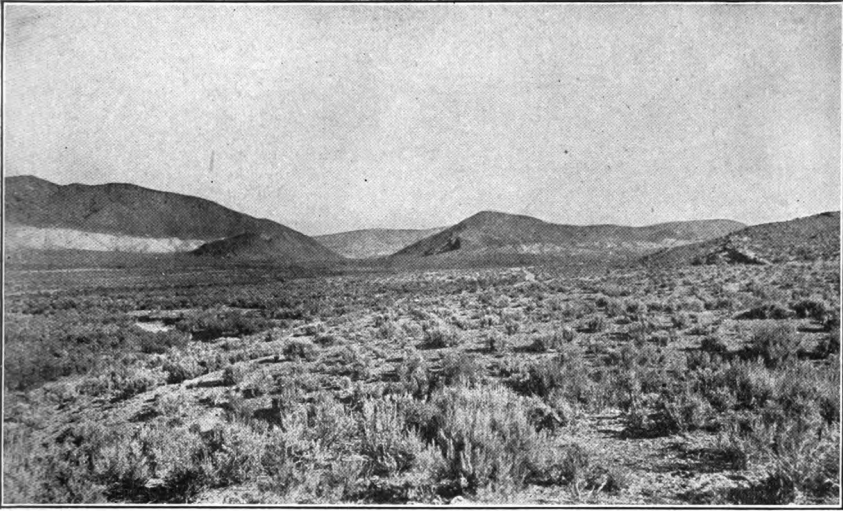
Day.	June.	July.	Aug.	Sept.	Day.	June.	July.	Aug.	Sept.
1913.					1913.				
1.....		6	4	84	16.....	9.4	4	4	2.5
2.....		6	4	173	17.....	7.1	4	4	8.2
3.....		6	4	45	18.....	8.2	4	4	4
4.....		6	4	4	19.....	8.2	4	4	10
5.....		5	4	4	20.....	8.2	10.5	4	4
6.....		5	4	4	21.....	6	8.2	4	2.5
7.....		5	4	4	22.....	6	2	8.2	8.2
8.....		5	4	4	23.....	7.1	4	4	6
9.....		6.7	4	4	24.....	6	4	4	4
10.....	19	6	4	4	25.....	6	4	6	4
11.....	19	4	4	4	26.....	8.2	4	8.2	4
12.....	13	4	4	4	27.....	20	4	6	2.5
13.....	13	4	4	6	28.....	19	4	8.2	4
14.....	14	4	4	6	29.....	14	4	10	4
15.....	12	4	4	4	30.....	12	4	6	4
					31.....		4	4	

Day.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
1913-14.												
1.....	4.0	4.0	4	6		6	19	64	130	26	11	6.3
2.....	4.0	2.5	4	6		8	19	60	138	26	11	6.3
3.....	4.0	2.5	4	6		10	25	130	130	24	9.6	6.3
4.....	4.0	2.5	4	8		8	40	130	122	22	8.5	6.3
5.....	4.0	2.5	4	8		8	44	130	126	22	8.5	6.3
6.....	2.5	2.5	4	8		8	40	122	122	21	8.5	6.3
7.....	2.5	2.5		8		9	44	114	122	21	8.5	6.3
8.....	1.7	2.5		8		10	40	122	114	21	8.5	7.4
9.....	1.7	2.5				16	40	122	100	21	8.5	6.3
10.....	2.5	4.0				22	40	122	87	21	8.5	6.3
11.....	4.0	4.0				25	40	130	82	21	8.5	6.3
12.....	2.5	2.5				29	40	122	76	20	8.5	6.3
13.....	2.5	2.5				29	40	130	76	20	9.6	6.3
14.....	2.5	2.5				32	48	138	68	20	9.6	6.3
15.....	2.5	4.0				36	48	130	63	18	8.5	6.3
16.....	2.5	6.0				44	52	154	63	18	8.5	6.3
17.....	2.5	4.0				40	72	146	55	20	8.5	6.3
18.....	2.5	4.0				40	57	138	51	20	8.5	6.3
19.....	2.5	4.0				44	48	130	51	32	8.5	6.3
20.....	2.5	4.0			36	44	67	150	53	40	6.3	6.3
21.....	2.5	2.5			25	44	57	158	53	55	6.3	5.2
22.....	2.5	2.5			13	48	48	166	47	20	6.3	7.4
23.....	2.5	2.5			9	48	52	162	45	16	11	7.4
24.....	2.5	4.0			6	44	57	154	40	15	8.5	8.5
25.....	2.5	2.5			4	62	52	138	36	14	7.4	9.6
26.....	2.5	2.5			2.5	52	57	122	32	14	6.3	11
27.....	4.0	6.0			6	57	52	100	51	14	5.2	7.4
28.....	2.5	6.0	4		6	52	62	106	32	14	5.2	7.4
29.....	2.5	6.0	5			19	60	110	32	14	6.3	7.4
30.....	2.5	4.0	6			19	64	106	30	12	6.3	7.4
31.....	2.5		6			19		138		12	6.3	

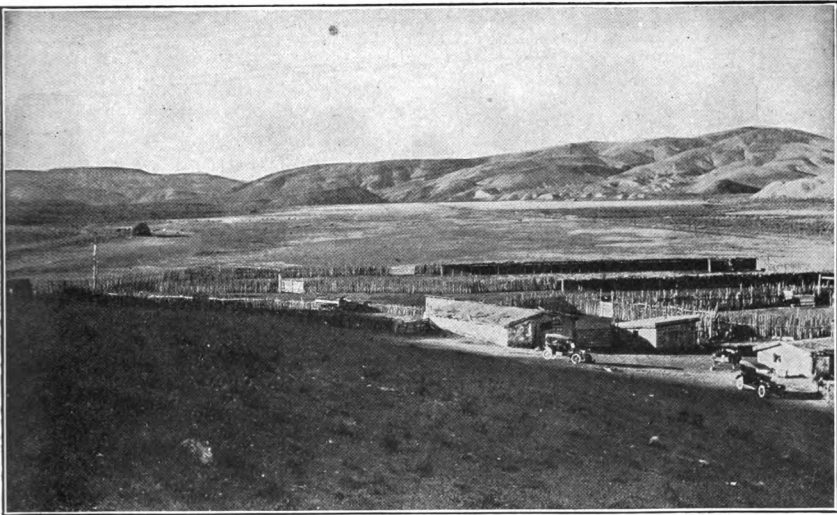
Daily discharge, in second-feet, of Reese River above Illinois Creek for the years ending Sept. 30, 1913-1916—Continued.

Day.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
1914-15.												
1.....	5.5	7.0	-----	-----	-----	7.0	28	69	118	35	17	-----
2.....	5.5	7.0	-----	-----	-----	7.0	28	62	128	35	17	-----
3.....	5.5	7.0	-----	-----	-----	8.0	28	62	128	35	16	-----
4.....	5.5	7.0	-----	-----	-----	8.0	30	62	128	36	16	-----
5.....	5.5	7.0	-----	-----	-----	8.0	31	65	118	36	14	-----
6.....	5.5	7.0	-----	-----	-----	7.0	32	69	101	35	14	-----
7.....	5.5	7.0	-----	-----	-----	7.0	34	71	86	35	14	-----
8.....	5.5	7.0	-----	-----	-----	7.0	34	71	69	34	-----	-----
9.....	5.5	7.0	-----	-----	-----	7.0	34	73	69	31	-----	-----
10.....	5.5	7.0	-----	-----	-----	7.0	34	69	69	27	-----	1.7
11.....	5.5	-----	-----	-----	-----	7.0	34	73	67	25	-----	1.5
12.....	5.5	-----	-----	-----	-----	7.0	34	73	67	21	-----	2.3
13.....	4.5	-----	-----	-----	-----	7.0	37	69	67	21	-----	2.3
14.....	3.5	-----	-----	-----	-----	11	40	73	62	20	-----	2.3
15.....	5.5	-----	-----	-----	-----	11	42	73	62	20	-----	2.5
16.....	5.5	-----	-----	-----	-----	12	43	78	60	20	-----	2.7
17.....	5.5	-----	-----	-----	-----	12	59	80	59	19	-----	2.7
18.....	5.5	-----	-----	-----	-----	13	57	73	58	19	-----	2.3
19.....	5.5	-----	-----	-----	-----	12	65	73	56	19	-----	2.3
20.....	7.0	-----	-----	-----	-----	12	65	69	54	21	-----	2.7
21.....	7.0	-----	-----	-----	-----	12	62	65	52	22	-----	2.7
22.....	5.0	-----	-----	-----	-----	13	62	62	51	22	-----	2.5
23.....	5.0	-----	-----	-----	-----	13	62	65	50	21	-----	2.7
24.....	6.0	-----	-----	-----	-----	13	65	69	48	21	-----	2.7
25.....	7.0	-----	-----	-----	-----	13	65	78	47	20	-----	3.1
26.....	7.0	-----	-----	-----	-----	13	62	78	47	19	-----	3.1
27.....	7.0	-----	-----	-----	-----	13	65	78	47	19	-----	3.1
28.....	9.0	-----	-----	-----	-----	25	62	78	40	18	-----	3.1
29.....	7.0	-----	-----	-----	-----	25	69	88	37	17	-----	3.1
30.....	7.0	-----	-----	-----	-----	28	65	101	36	17	-----	3.1
31.....	7.0	-----	-----	-----	-----	30	-----	105	-----	17	-----	-----
1915-16.												
1.....	3.1	-----	-----	-----	-----	-----	-----	-----	36	11	3.5	3.1
2.....	3.1	-----	-----	-----	-----	-----	-----	-----	40	12	3.5	2.9
3.....	3.1	-----	-----	-----	-----	-----	-----	-----	37	12	3.5	2.7
4.....	2.9	-----	-----	-----	-----	-----	-----	-----	39	11	3.5	2.5
5.....	3.1	-----	5.5	-----	-----	-----	-----	-----	41	8.5	3.5	2.5
6.....	3.1	-----	4.5	-----	-----	-----	-----	-----	43	7.6	3.5	2.5
7.....	2.9	5.5	4.5	-----	-----	-----	-----	65	44	8.0	3.5	1.9
8.....	3.1	5.5	5.1	-----	-----	-----	-----	64	47	8.5	3.5	1.7
9.....	3.1	5.5	5.1	-----	-----	-----	-----	63	46	7.9	3.5	1.5
10.....	3.9	5.5	5.3	-----	-----	-----	-----	60	46	8.5	3.5	1.9
11.....	4.7	5.5	5.3	-----	-----	-----	-----	58	47	8.5	3.5	2.0
12.....	5.5	5.5	-----	-----	-----	-----	-----	56	46	11	3.5	2.2
13.....	5.5	5.1	-----	-----	-----	-----	-----	54	46	12	3.5	2.1
14.....	5.5	4.7	-----	-----	-----	-----	-----	52	40	10	3.5	2.1
15.....	5.3	4.7	-----	-----	-----	-----	-----	50	40	8.5	3.5	1.9
16.....	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
18.....	5.1	4.3	-----	-----	-----	-----	-----	49	40	8.5	3.5	1.9
17.....	5.1	4.1	-----	-----	-----	-----	-----	48	33	8.5	3.5	2.3
19.....	5.1	4.3	-----	-----	-----	-----	-----	48	26	7.9	3.5	2.3
18.....	-----	3.9	-----	-----	-----	-----	-----	48	19	8.5	3.5	2.3
20.....	-----	3.5	-----	-----	-----	-----	-----	48	24	8.5	3.1	2.5
21.....	-----	5.1	-----	-----	-----	-----	-----	48	23	8.5	3.1	2.7
22.....	-----	5.1	-----	-----	-----	-----	-----	47	22	7.9	3.1	2.7
23.....	-----	5.3	-----	-----	-----	-----	-----	48	21	7.3	3.0	2.7
24.....	-----	5.1	-----	-----	-----	-----	-----	48	20	6.7	2.9	2.3
25.....	-----	5.5	-----	-----	-----	-----	-----	48	19	5.9	2.9	2.7
26.....	-----	5.1	-----	-----	-----	-----	-----	47	19	5.5	2.8	3.1
27.....	-----	5.5	-----	-----	-----	-----	-----	44	12	5.1	2.7	2.6
28.....	3.5	5.5	-----	-----	-----	-----	-----	40	12	5.5	3.1	2.0
29.....	-----	5.5	-----	-----	-----	-----	-----	40	12	4.5	3.1	1.5
30.....	-----	5.5	-----	-----	-----	-----	-----	39	12	3.5	3.1	1.5
31.....	-----	-----	-----	-----	-----	-----	-----	36	-----	3.5	3.1	-----

NOTE.—Discharge estimated as follows: Dec. 7-27, 1913, 3 second-feet; Jan. 9-31 and Feb. 1-19, 1914, 5 second-feet; Aug. 8-31, 1915, 10 second-feet; Sept. 1-9, 1915, 3.4 second-feet; Oct. 19-27, 1915, 4.3 second-feet; Oct. 29-31, 1915, 3.8 second-feet; Nov. 1-6, 1915, 4.9 second-feet; Dec. 1-4, 1915, 5.5 second-feet. No records obtained Nov. 11, 1914, to Feb. 28, 1915, and Dec. 12, 1915, to May 6, 1916.



4. HEAD OF REESE RIVER CANYON, SHOWING TERTIARY LAKE BEDS ON EACH SIDE.



B. REESE RIVER VALLEY, LOOKING DOWNSTREAM FROM JAMES LITSTER'S RANCH; TERTIARY LAKE BEDS ON THE RIGHT.

GROUND WATER IN REESE AND HUMBOLDT RIVER BASINS, NEV. 107

Monthly discharge of Reese River above Illinois Creek near Berlin, Nev., for the years ending Sept. 30, 1913-1916.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1913.				
June 10-30.....	20	7.1	11.2	467
July.....	10.5	4.0	4.89	301
August.....	10	4.0	4.80	295
September.....	173	2.5	14.2	845
The period.....				1,910
1913-14.				
October.....	4	1.7	2.79	172
November.....	6	2.5	3.47	206
December.....	6		3.48	214
January.....	8		5.58	343
February.....	36	2.5	7.23	402
March.....	57	6	29.7	1,830
April.....	72	19	47.5	2,830
May.....	166	60	127	7,810
June.....	138	30	74.2	4,420
July.....	55	12	21.1	1,300
August.....	11	5.2	8.1	498
September.....	11	5.2	6.86	408
The year.....				20,400
1914-15.				
October.....	9.0	3.5	5.89	362
November 1-10.....	7.0	7.0	7.0	139
March.....	30	7.0	12.1	744
April.....	69	28	47.6	2,830
May.....	105	62	73.4	4,510
June.....	128	36	69.4	4,130
July.....	36	17	24.4	1,500
August.....	17		11.2	689
September.....		1.5	2.84	169
1915-16.				
October.....	5.5	2.9	4.09	251
November.....	5.5	3.5	5.01	298
December 1-11.....	5.5	4.5	5.21	114
May 7-31.....	65	36	49.9	2,220
June.....	47	12	31.7	1,890
July.....	12	3.5	8.08	497
August.....	3.5	2.7	3.31	204
September.....	3.1	1.5	2.29	136

Measurements of the discharge of Reese River at several points made by the writer in September, 1916, and by L. W. Jordan in June, 1917, are given in the following table:

Miscellaneous discharge measurements of Reese River at several points.

Date.	Point of measurement.	Discharge in second- feet.
1916.		
Sept. 6	Mouth of canyon a few yards above Bell's ditch.....	2.67
6	Gaging station 75 yards above mouth of Illinois Creek.....	2.34
6	East of J. F. Bowler's house.....	.22
8	6 miles north of Whaley ranch.....	5.16
11	Welch's home ranch.....	Dry.
11	Tony Gondolfo's house.....	.56
11	Road bridge on Lincoln Highway west of Austin.....	2.90
13	Malloy's lower ranch.....	1.23
13	Mouth of Silver Creek; water flowing to head of field about $\frac{1}{2}$ mile above mouth of creek.....	Dry.
13	3 miles above mouth of Boone Creek (water from Bradley and Watercress springs).....	.05
13	Mouth of Boone Creek.....	Dry.
Thence dry for the remainder of its course.		
1917.		
June 13	SW $\frac{1}{4}$ sec. 16, T. 12 N., R. 40 E., just above mouth of Illinois Creek, 2 miles above the Bell home ranch.....	58.0
14	In T. 15 N., R. 41 E., 1,600 feet downstream from Lander-Nye County line, opposite lone butte about 25 miles south of Austin.....	134
14	In T. 20 N., R. 43 E., at first highway bridge across Reese River on the Austin-Battle Mountain road near the Malloy ranch and 8 to 10 miles from Austin (water comes from marshy land 5 to 10 miles above and is very brackish).....	22.0
14	At mouth of Boone Canyon, 50 to 60 miles south of Battle Mountain (stream is dry at this point in years of average run-off).....	5-10

NOTE.—In June, 1917, Reese River was flowing into Humboldt River at Battle Mountain.

The principal streams in the basin are, from north to south, Mill, Fish, Boone, Silver, Big, Clear, and Stewart creeks. In September, 1916, all these streams were carrying water for some distance below the mouths of their canyons.

A record of the flow of Big Creek has been obtained by the United States Geological Survey at a gaging station half a mile above the Carter ranch and 14 miles southwest of Austin. The gage used was a vertical staff on the left bank 100 yards above the head gate of Carter's ditch, in sec. 9, T. 17 N., R. 43 E. The drainage area is about 12 square miles. The observer was Mae M. Carter. The daily and monthly discharges from October 12, 1913, to June 30, 1914, are given in the following tables:

Daily discharge, in second-feet, of Big Creek half a mile above Carter ranch, near Austin, Nev., for the period Oct. 12, 1913, to June 30, 1914.

Day.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.
1.....		4.3	4.1	4.1	4.1	4.1	4.1	5.7	8.4
2.....		4.1	4.1	4.1	4.1	4.1	4.3	5.7	8.4
3.....		4.1	4.1	4.1	4.1	4.1	4.5	6.0	8.4
4.....		4.1	4.1	4.1	4.1	4.1	4.7	6.0	8.4
5.....		4.1	4.1	4.1	4.1	4.1	4.9	6.0	8.4
6.....		4.1	4.1	4.1	4.1	4.1	5.1	6.0	9.0
7.....		4.1	4.1	4.1	4.1	4.1	5.2	6.0	10.8
8.....		4.1	4.1	4.1	4.1	4.1	5.4	8.4	9.6
9.....		4.1	4.1	4.1	4.1	4.1	5.6	8.4	9.0
10.....		4.1	4.1	4.1	4.1	4.1	5.7	8.4	9.0
11.....		4.1	4.1	4.1	4.1	4.1	5.7	8.4	9.0
12.....	4.3	4.1	4.1	4.1	4.1	4.1	5.7	8.4	9.0
13.....	4.3	4.1	4.1	4.1	4.1	4.1	5.7	8.4	9.6
14.....	4.3	4.1	4.1	4.1	4.1	4.1	5.7	6.0	9.0
15.....	4.3	4.1	4.1	4.1	4.1	4.1	5.7	6.0	9.6
16.....	4.1	4.1	4.1	4.1	4.1	4.1	5.7	6.0	9.6
17.....	4.1	4.1	4.1	4.1	4.1	4.1	5.7	6.0	9.6
18.....	4.1	4.1	4.1	4.1	4.1	4.1	5.7	6.0	9.6
19.....	4.1	4.1	4.1	4.1	4.1	4.1	5.7	8.4	9.6
20.....	4.1	4.1	4.1	4.1	4.1	4.1	5.7	6.0	9.6
21.....	4.1	4.1	3.9	4.1	4.1	4.1	5.7	6.0	9.6
22.....	4.1	4.1	3.9	4.1	4.1	4.1	5.7	7.2	9.0
23.....	4.1	4.1	3.9	4.1	4.1	4.1	5.7	8.4	9.6
24.....	4.1	4.1	3.9	4.1	4.1	4.1	5.7	8.4	10.2
25.....	4.1	4.1	3.9	4.1	4.1	4.1	5.7	8.4	9.6
26.....	4.1	4.1	3.9	4.1	4.1	4.1	5.7	8.4	9.6
27.....	4.1	4.1	3.9	4.1	4.1	4.1	5.7	6.0	9.6
28.....	4.1	4.1	3.9	4.1	4.1	4.1	5.7	6.0	9.6
29.....	4.1	4.1	3.9	4.1	.....	4.1	6.0	6.0	9.0
30.....	4.1	4.1	3.9	4.1	.....	4.1	6.0	6.0	9.6
31.....	.....	4.1	3.9	4.1	.....	4.1	.....	10.8	.....

Monthly discharge of Big Creek half a mile above Carter ranch, near Austin, Nev., for the period Oct. 12, 1913, to June 30, 1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
October 12-31.....	4.3	4.1	4.14	165
November.....	4.3	4.1	4.11	245
December.....	4.1	3.9	4.02	247
January.....	4.1	4.1	4.10	252
February.....	4.1	4.1	4.10	228
March.....	4.1	4.1	4.10	252
April.....	6.0	4.1	5.47	325
May.....	10.8	5.7	7.03	432
June.....	10.8	8.4	9.30	553
The period.....				2,700

Humboldt River carries only a small amount of water late in summer. The principal stream, besides Reese River, that is tributary to the Humboldt within the area shown on Plate VIII is Rock Creek.

A record of the flow of Rock Creek has been obtained by the United States Geological Survey at a point about 1½ miles above the Rock Creek ranch house, 9 miles northwest of Dunphy, and about 35 miles north of Battle Mountain. The gage used was a vertical staff near the left end of an old footbridge about a mile above the diversion dam at the mouth of the canyon, approximately in sec. 1, T. 37 N., R. 46 E. The drainage area has not been measured. The observer was W. H. Muffley. The daily and monthly discharges for May 13 to Sept. 30, 1915, are given in the following tables:

Daily discharge, in second-feet, of Rock Creek at Rock Creek ranch, near Battle Mountain, Nev., for the period May 13 to Sept. 30, 1915.

Day.	May.	June.	July.	Aug.	Sept.	Day.	May.	June.	July.	Aug.	Sept.
1.....		15	1.5	4.4	3.6	16.....	8.8	13			5.6
2.....		15	1.5	4.7	3.6	17.....	8.1	12	6.7		
3.....		15	1.5	5.0	3.6	18.....	10	12			
4.....		14	1.0	5.3	3.6	19.....	13	11			
5.....		13	.4	5.6	3.6	20.....	15	7			
6.....		13		5.8	4.0	21.....	17	2.7			
7.....		13	.4	6.0	4.2	22.....	15	3.6			
8.....		13		6.2	4.4	23.....	13	4.4			
9.....		12		6.4	4.4	24.....	14	4.4			
10.....		11		6.7	4.4	25.....	16	4.4	4.4		
11.....		12		6.7	4.4	26.....	17	3.6	4.4		
12.....		13		6.7	4.4	27.....	16	3.3	4.4		
13.....	12	13		6.7	4.4	28.....	15	3.0	4.4		
14.....	11	13			4.8	29.....	14	2.7	4.4	3.6	
15.....	9.5	13			5.2	30.....	12	2.1	4.4	3.6	
						31.....	11		4.4	3.6	

NOTE.—Discharge estimated as follows: July 8–16, 3.5 second-feet; July 18–24, 5.6 second-feet; Aug. 14–28, 5.2 second-feet; Sept. 17–30, 5 second-feet.

Monthly discharge of Rock Creek at Rock Creek ranch, near Battle Mountain, Nev., for the period May 13 to Sept. 30, 1915.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
May 13–31.....	17	8.1	13.0	491
June.....	15	2.1	9.57	569
July.....	6.7	.4	3.71	228
August.....	6.7	3.6	5.32	327
September.....	5.6	3.6	4.61	274
The period.....				1,890

Miscellaneous discharge measurements made by the writer during the reconnaissance are given in the following table:

Miscellaneous discharge measurements in Reese River and Humboldt River basins, Nev., 1916.

Date.	Stream and locality.	Discharge in second-feet.
Sept. 6	Bell's ditch 300 yards below its intake from Reese River.....	0.8
6	Stewart Creek at Schmaling's ranch.....	.2
6	Stewart Creek 3 miles above Schmaling's ranch.....	.6
6	Clear Creek at Gooding's ranch.....	.2
6	Silver Creek at upper (eastern) road crossing.....	.20
13	Boone Creek at Mrs. Litster's ranch.....	.15
13	Boone Creek at Boone Creek ranch.....	.10
14	Fish Creek at Fish Creek ranch.....	.60
15	Mill Creek at mouth of its canyon.....	.20
15	North Fork of Mill Creek 25 yards above its junction with South Fork.....	.15
15	South Fork of Mill Creek 25 yards above its junction with North Fork.....	.30
20-	Humboldt River at road crossing 1½ miles southwest of Kampos.....	1.75
21	Rock Creek at bridge at mouth of its canyon.....	.30
21	Rock Creek 1 mile above the bridge.....	.80

SOURCE AND DISCHARGE OF GROUND WATER.

Practically all the ground water of the Reese River valley is derived from the precipitation within the drainage basin. The bed-rock constitutes a relatively water-tight basin, which is deeply filled with unconsolidated deposits in which the ground water is stored. Some water is supplied to this underground reservoir directly by the precipitation on the valley lands, but the greater part is supplied by the run-off through the numerous canyons, whose water rapidly sinks in the loose materials of the alluvial slopes below the canyon mouths.

The contributions of water to the underground supply are offset by losses through percolation out of the basin, through evaporation and transpiration from moist areas, and through discharge of springs.

The underground percolation from the Reese River valley to Humboldt Valley is probably slight, because the gradient of the lower part of the Reese River valley is low.

In the areas of appreciable discharge through evaporation where the water table is within the capillary limit¹ of about 10 feet below the surface the evidence of constant evaporation is usually shown by the dampness of the ground, by alkaline deposits, or by the growth of certain plants, chiefly salt grass and various bushes. Ground water is less than 10 feet below the surface of nearly all the cultivated land in the Reese River basin. These lands are devoted chiefly to growing native hay, but there are a few fields of alfalfa. Along Humboldt River, however, much of the native-hay land is irrigated by ditches from the river, and the ground water

¹ Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 294, 1912. Meinzer, O. E., Geology and water resources of Big Smoky, Clayton, and Alkali Spring valleys, Nev.: U. S. Geol. Survey Water-Supply Paper 423, pp. 92-102, 1917.

is shown by wells to be at a somewhat greater depth than the probable limit of appreciable discharge through evaporation. The areas both of cultivated land and of ground-water discharge through capillarity are shown on Plate VIII (in pocket).

There are not many springs in the drainage basin of Reese River. Most of them are in the mountains and are supplied by rain and snow water from the adjacent slopes. Some of the springs in the lowlands, such as Mound Spring, the hot springs east of Fish Creek, and the hot springs in Buffalo Valley, are probably supplied by deep-seated water that rises along fault fractures and does not represent leakage from the valley fill. Antelope Spring and the springs southwest of it (see Pl. VIII, in pocket, and Pl. XI, *B*) and Bradley and Watercress springs seem to be supplied by water stored in materials of the Truckee formation, above the valley lowlands. Buffalo and Kane springs, in Buffalo Valley, are apparently supplied by water under artesian pressure stored in the alluvial slopes at the base of the Havallah Range. A spring (No. 12 on Pl. VIII) in the lowland southwest of Battle Mountain seems to be supplied from the water table, at a place where the ground surface is depressed a few feet below its mean level. The springs along the river channels near Tony Gondolfo's ranch, in the valley above Austin, represent the return of the underflow to the surface. The springs at Whaley's ranch issue from the alluvial slope on the west side of the lowland and discharge water stored in the unconsolidated material.

WATER TABLE.

Practically all the wells in the area at the time of examination are shown on Plate VIII, except those at Battle Mountain, where there are about 40 small flowing wells. Enough wells have not been sunk on the slopes bordering the lowlands to ascertain the depth to water beneath these slopes, but the valley areas within which the water table is less than 10 feet below the surface are shown on Plate VIII, and the depth to water in the wells examined is indicated.

From the shallow-water areas the water table rises toward the mountains on a grade considerably less than that of the surface, so that the depth to water increases rapidly with increased elevation above the lowlands. The only measurement obtained that affords definite information as to the slope of the water table was that of the well at the O'Toole ranch (No. 83 on Pl. VIII). The depth to water there is 80 feet, and the mouth of the well is about 130 feet above the lowland near the river, a mile to the west, where the depth to water is about 10 feet. The water table in this vicinity therefore seems to rise to the east at the rate of 60 feet to the mile, having a gradient about half as steep as that of the surface of the ground. The slope of the water table in different parts of the basin depends on the sup-

ply of ground water, the slope of the surface, and the character of the material in which the water occurs. The single observation given can not be applied indiscriminately to other parts of the basin.

QUANTITY OF GROUND WATER.

Studies of the amount of ground-water intake were not made by measurements of the perennial and intermittent streams, nor of the ground-water discharge by a survey and detailed examination of the areas where the water table is within 10 feet of the surface. Neither are figures at hand to show the depth and porosity of the valley fill. Any numerical estimate of the total amount of ground-water stored in the valley fill of the Reese River basin would therefore seem to be a mere guess. As the annual supply of surface water is not sufficient to make the river perennial, even in the upper half of its course, the annual intake of ground water must be comparatively small, though records of drilled wells indicate that the valley fill is several hundred feet deep and therefore has large storage capacity. Test wells show that the materials are prevailing fine grained, however, and that the rate at which water can be recovered by pumping is slow.

The depth to water is less in the upper part of the Reese River valley, south of the Reese River canyon, than it is in the lowlands north of the canyon. The amount of available ground water is therefore presumably greater in the upper part of the valley than in the lower part. Antelope Valley probably contains a relatively small amount of ground water, for its drainage basin is small and its lowland seems dry. Buffalo Valley receives considerable water from the high slopes of the Havallah Range and from the drainage basin that extends northward between Battle Mountain and the Havallah Range. It apparently has a more plentiful supply of ground water than Antelope Valley, and its water table is less than 10 feet below the surface in the lowest part of the valley.

ARTESIAN CONDITIONS.

In the town of Battle Mountain drilled or bored wells that yield artesian flows under small head furnish the water supply. In 1916 43 flowing wells were reported in the town and vicinity. There are said to be four horizons of flowing water, at about 100, 180, 250, and 300 feet below the surface. The greatest static head encountered is reported to have been about 16 feet above the surface. The artesian head has declined noticeably since the Southern Pacific Co. drilled a deep well in the town and has been pumping large quantities of water from it to supply locomotives. On the north side of Humboldt River four flowing wells (Nos. 2, 3, 4, and 18, Pl. VIII), were drilled prior to 1904, and in 1916 each of these was flowing a few

gallons a minute. On the Jenkins Martin ranch, 9 miles south of Battle Mountain, there were three wells that barely flowed.

In the Reese River valley above the canyon several wells have been drilled in attempts to develop artesian flows to supply stock-watering troughs. A well (No. 56) drilled 210 feet deep near the border of the lowland, $1\frac{1}{2}$ miles north of Boone Creek, struck water under slight artesian head, sufficient to bring it within 3 feet of the surface, or about 8 feet above the ground-water level. On James Litster's ranch a casing sunk 15 feet into a small spring (No. 54) yields a slight flow, and in 1916 a well was being drilled a few yards from it, in an attempt to obtain a larger flow. A well (No. 63) drilled near Bradley Springs yields a small flow. On the Walsh home ranch a flow of 8 gallons a minute was obtained at about 450 feet. On W. S. Carter's desert claim a 200-foot well (No. 78) obtained a flow of 10 gallons a minute, but another well 505 feet deep, drilled on the same tract, failed to strike flowing water. Fred Ahlers has two wells (Nos. 80 and 81) 6 feet apart and 107 and 110 feet deep. The shallower one yields a slight flow. In the other the water stands 2 feet below the surface. On the Walsh Hess ranch a well was drilled 860 feet deep in an unsuccessful attempt to develop a flow.

Above the Reese River canyon the prospects of obtaining flowing wells are best in the lowlands near the river, as shown by the success of the well at the Walsh home ranch and to a less extent by that on W. S. Carter's desert claim. The Ahlers wells seem to be at about the eastern limit of artesian flow. The wells drilled in this part of the valley encountered only clay and very fine sand, the flows being obtained from a fine black sand. None of the wells encountered coarse material that might readily yield water.

In the places along the Reese River valley where extensive alluvial slopes exist small supplies of flowing water can probably be obtained by wells put down along the lower margins of these slopes. It seems improbable that the underflow of Reese River itself develops sufficient head to yield artesian flows. The underflow of Big Creek and adjacent canyons probably supplies the Carter and Ahlers flowing wells and also the one at Walsh's home ranch. Flows can probably be obtained along the east border of the lowlands between Italian Creek and Watercress Springs, on the west border near Fish Creek, on the east side between Mill Creek and Crum Creek, and near the playa in Antelope Valley. In Buffalo Valley Buffalo Springs and Kane Springs seem to be supplied by water under artesian pressure below the alluvial slopes to the west. In the vicinity of Battle Mountain and probably along the valley of Humboldt River above and below this town flowing water under a small static head can doubtless be obtained over a much greater area than is at present outlined by flowing wells.

Throughout the Reese River basin and adjacent portions of the Humboldt basin the artesian head is small and the water-bearing beds consist largely of fine sand. The prospects of developing flowing wells of large yield are therefore not encouraging.

QUALITY OF GROUND WATER.

GENERAL CHARACTER.

Analyses of samples of water from wells and springs in the Reese River basin (see table, pp. 125-129) show that the waters are quite as good as those in other valleys of the arid West. Although the grade of Reese River is not great and its discharge is small, the basin as a whole is well enough drained to prevent the accumulation of alkali in the valley lands. Most of the waters are satisfactory for domestic use and for irrigation, but more than half of those examined would form excessive quantities of scale or cause foaming in boilers.

The water from most of the drilled wells is more satisfactory for ordinary uses than that obtained from shallow dug wells, and the water obtained from springs is apparently poorer than that from the deep wells but better than that from the shallow wells. This relation is shown by the following table:

Average, maximum, and minimum content of chemical constituents in water from dug wells, drilled wells, and springs.

[Parts per million except as otherwise designated.]

	Dug wells (21).			Springs (6).			Drilled wells (9). ^a		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
Silica (SiO ₂).....	40	67	17	60	117	35	39	73	17
Iron (Fe).....	.03	.30	.02	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Calcium (Ca).....	64	125	21	60	123	30	60	157	23
Magnesium (Mg).....	17	42	6.7	9.3	36	10	18	52	Tr.
Sodium and potassium (Na + K) ^b	131	587	32	123	327	16	32	50	2.8
Carbonate radicle (CO ₃).....	14	168	.0	2.3	14	.0	9.5	88	.0
Bicarbonate radicle (HCO ₃).....	304	793	107	392	761	129	222	670	44
Sulphate radicle (SO ₄).....	111	601	20	86	227	22	56	89	24
Chloride radicle (Cl).....	78	557	16	28	50	16	25	84	6.0
Nitrate radicle (NO ₃).....	19	80	.0	1.0	6.0	.0	.0	.0	.0
Total dissolved solids at 180°C.....	638	2,133	281	580	1,032	252	370	694	235
Total hardness as CaCO ₃ c.....	229	394	80	188	455	75	223	606	58
Scale-forming constituents c.....	260	420	130	250	460	180	250	580	120
Foaming constituents c.....	350	1,600	90	330	880	43	87	140	8
Alkali coefficient (inches) c.....	23	79	24	30	100	2.5	100	290	19
Depth of well (feet).....	26	108	7	.....	.....	.....	254	500	25
Depth to water (feet).....	20	80	6	.....	.....	.....	(d)	16	(d)

^a Well No. 54 omitted; sample contained vegetable matter; water probably of surface origin.

^b Calculated.

^c See standards for classification given in U. S. Geol. Survey Water-Supply Paper 398, pp. 50-81, 1916.

^d Seven of the nine drilled wells are flowing.

WATER FROM DUG WELLS.

The effect of evaporation and transpiration, the processes that tend to concentrate natural waters, is shown in the analyses mainly by the greater amount of total dissolved mineral matter, most of which consists of the more soluble salts, for the less soluble salts are more readily precipitated. As a net result, therefore, of evaporation and transpiration the water remaining in the ground contains relatively more of the alkalis and less calcium and magnesium than water not thus concentrated. As these processes are active at the surface of the ground, the water of many shallow wells contains large amounts of sodium and potassium, carbonate, bicarbonate, sulphate, and chloride and is therefore high in total solids.

The content of total solids in the water from dug wells in the Reese River basin ranges from 281 to 2,133 parts per million; the average is 638 parts. The proportions of calcium and magnesium are relatively large, as would be expected from the fact that the rocks of the region are calcareous, but in many of the waters the alkalis greatly exceed the alkaline earths. Carbonate is present in the water of 8 of the 21 dug wells, and in that of one of the wells it amounts to 168 parts per million. The content of bicarbonate ranges from 107 to 793 parts per million, averaging 304 parts. Sulphates and chlorides are high in some of the waters, but in only a few are they present in excess of other acid radicles.

The presence of organic matter in excessive amounts is worthy of mention. Nitrate is normally absent from ground waters or is present in only small amounts, for rocks as a rule contain only traces and soils but little more. The nitrate in these well waters is probably derived from decayed organic matter and indicates pollution by sewage, which may seep from near-by barnyards, privies, or cesspools through the ground and into the wells, or may fall into the wells through open tops or through covers that are not water-tight and dirt-proof. Many shallow wells are thus contaminated, and if analyses of waters from such wells show that nitrate amounts to more than a few parts per million the sanitary conditions surrounding the wells should be carefully examined, possible sources of pollution should be removed, covers should be so fitted that waste water will drain away from rather than into the well, and farm animals should be kept at a safe distance.

Most of the waters are of the carbonate type, ten (Nos. 5, 37, 43, 50, 72, 74, 82, 83, 85, and 98) being calcium-carbonate and eight (Nos. 6, 7, 8, 20, 46, 55, 66, and 87) sodium-carbonate. Of the three remaining, two (Nos. 34 and 49) are sodium-chloride waters and one (No. 32) is a calcium-sulphate water.

Six of the waters (Nos. 32, 34, 37, 49, 66, and 72) have been classed as bad for domestic use, chiefly because of their hardness but partly because they contain excessive amounts of chloride and sulphate.

The other fifteen (Nos. 5, 6, 7, 8, 20, 43, 46, 50, 55, 74, 82, 83, 85, 87, and 98) range in quality from fair to good for drinking and cooking, so far as mineral content is concerned, though they may be polluted, as has been suggested in connection with the discussion of nitrate: None of the waters can be classed as good for use in boilers, and only four (Nos. 7, 20, 87, and 98) have been classed as fair; the rest (Nos. 5, 6, 8, 32, 34, 37, 43, 46, 49, 50, 55, 66, 72, 74, 82, 83, 85, and 98) are poor or very bad, for they contain in too great amount constituents that cause incrusting and foaming, and the water of one well (No. 32), if used for making steam, would probably corrode the boiler.

Although many of these waters are not satisfactory for domestic supplies or for use in boilers, most of them can be used for irrigation without danger to crops from deposition of alkali. Three of the waters (Nos. 34, 49, and 55) are classed as poor for irrigation, but the first two are sodium-chloride waters that would probably leave in the soil the less injurious "white alkali," and the third is a sodium-carbonate water which might leave "black alkali" upon evaporation. This water (No. 55) might be used to grow some of the crops more resistant to alkali if carefully applied to land that had been treated with gypsum and was adequately drained.

WATER FROM SPRINGS.

Analyses of samples of water from six springs in this area apparently indicate that the spring waters are not so highly mineralized as the water from dug wells, the average content of total solids in water from springs being 580 parts per million, whereas the average for water from dug wells is 638 parts per million. The average content of silica and bicarbonate is higher in the spring waters than in the water from the dug wells, but that of the other constituents is lower. The water of only one spring (No. 90) is reported to contain nitrate, and that water only 6.0 parts per million, an amount that is small when compared with such an amount as 80 parts per million in the water of the shallow dug wells (p. 114).

The waters of three of the springs (Nos. 24, 60, and 90) are calcium-carbonate, and three (Nos. 41, 47, and 48) are sodium-carbonate in character. The water of well 24 has been classed as bad for domestic use because of its hardness (455 parts per million), but the other five (Nos. 41, 47, 48, 60, and 90) are fair or good for drinking and cooking. In general they are not well suited for use in boilers, though the water from springs 60 and 90 would form in boilers only a moderate amount of soft scale.

Two of the spring waters (Nos. 41 and 48) contain such quantities of alkalies as to be unsatisfactory for use for irrigation unless on lands that are exceptionally well drained. The water from spring 41

is not now used for irrigating crops, but that from spring 48, although used for irrigation, is likely to cause trouble if precautions are not taken to prevent accumulation of alkali in the soil. Water from the other four springs (Nos. 24, 47, 60, and 90) is better adapted for use in irrigating.

WATER FROM DRILLED WELLS.

Samples of water from ten drilled wells in the area covered by this report were analyzed. Eight of the wells exceed 100 feet in depth; two (Nos. 39 and 54) are 25 and 15 feet deep, respectively. Although No. 54 is a drilled well the water from it is evidently derived from surface run-off or from material lying little below the surface, for it is, totally unlike that from other drilled wells, contains much mineral matter, largely alkalies and bicarbonate, is only fair for domestic use, and could not be used satisfactorily in boilers or for irrigation without special precautions. The analysis has therefore not been included with the others in the table on page 114.

In almost all the analyses of the water from drilled wells the averages of constituents (table, p. 114) are lower than those shown by analyses of the water from dug wells. This statement is especially true of the alkali ($\text{Na} + \text{K}$) and the acid radicles (CO_3 , HCO_3 , SO_4 , Cl , and NO_3). In only one of the samples, that from the shallow well (No. 54) discussed above, was nitrate reported present. This apparent absence of the oxidation products of decayed organic matter gives considerable assurance that the waters from these drilled wells are free from contamination by sewage and are therefore safe for human consumption.

Six of the drilled wells (Nos. 17, 30, 39, 76, 78, and 80) yield calcium-carbonate waters, two (Nos. 4 and 22) sodium-carbonate waters, and the remaining well (No. 26) a sodium-sulphate water.

Only one of the nine waters averaged (that from well 80) is classed as bad for domestic use; the rest are either good or fair. Well 39, on the Indian ranch, is an exception to the rule that shallow wells are distinctly inferior to deeper ones, so far as quality of water is concerned. This well is only 25 feet deep, yet its water is but moderately mineralized, is fair for domestic use, and is good for irrigation; it might be satisfactorily used in boilers if no better supply were available, but if so used should be softened by treatment with lime.

The average content of total solids in the nine wells—370 parts per million—is decidedly lower than that for springs, which is 580 parts, and approximately 50 per cent of the average for dug wells, which is 638 parts per million.

SUMMARY OF QUALITY OF WATER.

1. Dug wells furnish water that is generally satisfactory, so far as mineral content is concerned, for domestic use, good or fair for irrigation, and poor for use in boilers. If the water is to be used for domestic supply, such wells must be carefully located and protected from pollution.

2. The water from springs is usually satisfactory for domestic use, poor for boilers, and better than that from dug wells for irrigation.

3. The deeper drilled wells, if properly cased to exclude water from near the surface, will yield water that is more satisfactory for general uses than either dug wells or springs.

WATER SUPPLIES.**DOMESTIC SUPPLIES.**

Most of the residents in and near Battle Mountain are supplied from flowing wells 2 or 3 inches in diameter, but a few are supplied by shallow wells that tap only the superficial ground water. In the Reese River basin water on the ranches is obtained chiefly from shallow dug wells, but springs supply a few ranches, including the Wilson ranch (No. 24, Pl. VIII), the Hotspring ranch (No. 48), and the Warner ranch (No. 90). A few others, as the Fish Creek and Boone Creek ranches, are supplied by perennial streams.

PUBLIC SUPPLY.

The only public supply in the area is that of Austin. Water for this town is furnished by a spring on the higher slopes to the south-east and is piped down to a tank and a reservoir on a knoll in the town. Thence it is distributed through several lines of pipe. The yield of the spring was not learned, but it is said to be ample throughout the year for the needs of the town.

STOCK SUPPLIES.

In the mountains there are a few small springs that supply the range cattle in the later part of the summer, when most of the canyons become dry. In the lowlands Reese River furnishes the principal stock supply where its flow is perennial, and in the upper part of the valley flowing wells are obtained. In the lower part of the Reese River valley there is in summer a serious lack of watering places, however, and although there has been some attempt to overcome this lack by means of flowing wells, efforts to obtain flows have in most localities not proved successful. It seems probable that in the lower part of the Reese River valley pumped supplies must be relied upon, perhaps by the use of windmills. The water from flowing wells is exceptionally good stock water for winter use because it is comparatively warm and hence does not chill the animals.

INDUSTRIAL SUPPLIES.

Industrial supplies in the area were in 1916 limited to those used by the railroad companies. At Battle Mountain the Southern Pacific Co. has a 480-foot well and a pumping station which supplies the needs of locomotives and of cattle that are being shipped. The Western Pacific Railroad has a shallow dug well of large diameter at Kampos, which supplies the locomotives, and another shallow well of large diameter at Dunphy, where the watering of cattle being shipped on this line is in part done.

IRRIGATION FROM WELLS.

DEVELOPMENTS.

In 1916 irrigation from wells had been attempted in only two places in the area examined—on the desert claim of Ramón Oyarbide, 8 miles south of Battle Mountain, and on the desert claim of W. S. Carter, 8 miles southwest of Austin. Mr. Oyarbide had two small pumping plants, consisting of distillate engines and centrifugal pumps, lifting from the ground-water level, about 15 feet below the surface. Mr. Carter was depending on a flowing well for the irrigation of a portion of his claim. Both developments had been made only a short time, and no crop had been planted on either claim.

Although there are a number of flowing wells in the Reese River and Humboldt River basins, the examination indicates that the artesian head is small and that flows sufficient for irrigation probably can not be obtained. Irrigation with ground water must be accomplished chiefly by pumping.

WELL CONSTRUCTION.

Water can be easily obtained by digging wells in the lower parts of the Reese River and Humboldt River valleys, but such wells can not be cheaply sunk to depths very far below the water table, because of the necessity of curbing. Dug wells sunk only a short distance below the level at which water is struck can not furnish large supplies. Wells sunk to obtain artesian flows for domestic use or for stock or to obtain supplies for irrigation by pumping probably will have to be put down more than 100 feet.

Ordinary cable drilling rigs have been used with good results in sinking wells in this region. Hydraulic outfits, in which water is pumped down through hollow drill rods and comes up on the outside, bringing the drillings with it, are well suited for cheap, efficient, and rapid work in the deep, fine-grained, unconsolidated deposits of the Reese River and Humboldt River basins. In drilling by this method the ascending muddy water plasters the walls of the well and produces an effective coating. Even in a deep well in soft

materials it is generally not necessary to insert casing until drilling has been completed; and in some localities where the materials are clayey, casing of the lower part of the well is unnecessary. Hydraulic machines are much used for sinking wells 2 to 4 inches in diameter, and these could be put down cheaply in order to test the water supply prior to undertaking irrigation development. The machines are, however, too light for the efficient sinking of wells 6 inches or more in diameter, and wells of relatively large diameter are desirable for pumping supplies. The ordinary cable tools are probably best adapted to drilling wells for irrigation in this area.

For pump wells 6 inches in diameter or larger "stovepipe" casing of heavy sheet iron forms a very serviceable and relatively cheap casing. It is made of 2-foot sections, of two sizes, one of which slips snugly over the other, with the ends breaking joints. The casing is built up and forced down the well as drilling progresses. As casing of this kind leaks at the joints it is not suitable for use in flowing wells, in which the more expensive but water-tight screw casing must be used. In pump wells the casing should be perforated at every satisfactory water-bearing bed, either before or after the insertion of the casing in the well. Where flowing water is encountered in valley fill there are usually satisfactory artesian beds at two or more horizons, and in order to get the maximum yield all of them should be penetrated by the drill, and the casing should be perforated throughout the thickness of each artesian bed.

Quicksand does not seem to have been encountered in quantities so large as to seriously hinder drilling in wells that have been sunk in the area examined. The fine materials seem to consist of clay or sandy clay and to be easily handled by experienced drillers.

RECOVERY OF WATER.

The depth to which it is advisable to drill wells to be pumped for irrigation differs greatly from place to place, depending on the character of the valley fill. The available data indicate that along the borders of the Reese and Humboldt river valleys it probably will not be of advantage to sink more than 200 or 300 feet. In the lower lands, near the troughs of the valleys, sufficient water for small pumping plants can probably be obtained from wells less than 200 feet deep, if they are properly cased and perforated. In places where coarse water-bearing material is obtained at shallow depths two or more relatively shallow drilled wells may yield a larger total supply than one deep well. For economy in pumping, wells that are near each other are usually connected to the same pump.

Care should be taken to insure as large a recovery as possible from each well by perforating the casing at every suitable water-bearing bed with as many and as large perforations as is practicable, and

in finishing the well to clean it thoroughly by strong pumping in order to remove the fine sediments and thus produce a strainer of gravel and coarse sand around the casing. Large yields keep down the cost of well construction per unit of water developed and, by lessening the drawdown, keep down the cost of lifting water.

Horizontal centrifugal pumps are generally used in areas where the pumping lift is not great, and as the ground-water level is at shallow depths throughout most of the lowlands of the Reese River and Humboldt River valleys such pumps will doubtless prove best adapted to raise water for irrigation in this region. The pump should be set in a pit just above the water level, so as to work under as low a suction lift as possible, and the size of the pump should be carefully chosen with respect to the capacity of the well. Care should also be taken that the discharge from the pump is no higher than is necessary, for the power required for pumping depends on the height to which the water is lifted, and the cost of power is one of the largest costs in irrigation by pumping.

For the Reese River basin, where electric power is not available for pumping, distillate or oil engines are probably the most suitable power units. The cost of pumping depends largely on the efficiency of the pumping plant, and after the size of pump best adapted to the capacity of the well and the pumping lift has been determined the engine should be properly chosen with respect to it. An engine that is larger than is necessary to run the pump or one that is too small to run the pump at proper speed will make the cost of pumping needlessly high. Most of the manufacturers of pumping machinery have in their service experts who will assist farmers in planning installations suitable to the local conditions of ground water and the irrigation development that is to be undertaken.

AREAS.

The lands that seem to be best adapted to irrigation by wells in the upper part of the Reese River valley are along the east side between Big Creek and Austin. Farther up and down the valley and also along the west side the soil is composed to a large extent of clay, probably derived from the Truckee formation, and is of poorer quality than the alluvial material along the bases of the fans of Big Creek and adjacent canyons. Much of the meadow land along the river between the Walsh Hess ranch and Ledlie could probably be made more productive than it is at present by following irrigation with flood water by irrigation with pumped water. The land in the lower part of the Reese River valley, along the east side, below the Hotspring ranch, although covered largely with an unpromising growth of arid-land shrubs, can be made productive by irrigation, as is shown by a large alfalfa field, irrigated by stream water at the

Jenkins home ranch. The lands near the river channel are so barren as to make it unwise to attempt irrigation unless careful tests show that both the soil and the ground water available for irrigation are so free from alkali that it will not cause trouble. Antelope Valley is rather barren, but there may be a supply of ground water of sufficient purity for use in irrigation within easy pumping reach. The lower part of Buffalo Valley is an alkali-incrusted flat, but the gentle slopes that border it on the west and north are probably underlain by water of fair quality within 50 feet of the surface; and pumping irrigation might be developed to a considerable extent on these lands. Along the valley of Humboldt River shallow water is available for pumping, and in some places this water can doubtless be advantageously developed for irrigation as auxiliary to the surface-water supply.

CROPS AND MARKETS.

The short growing season, with cold spring and autumn, limits the variety of crops that can be grown in the region, and the lack of transportation facilities in parts of the area examined also places restrictions on the kinds of crops that can be profitably grown. Austin and Battle Mountain furnish only small markets for such hardy vegetables as can be grown. The chief agricultural interest is directly related to stock raising, principally of cattle, and alfalfa promises to be the most profitable irrigated crop, to be grown for local use as winter feed.

• WELLS AND SPRINGS.

The following list is believed to include all the important springs and nearly all the wells, except some of those in Battle Mountain, that had been sunk at the time the region was examined. The figures giving the depth to the water table at each well probably show with fair accuracy the depth to water in the vicinity of the well. It should be noted that the figures indicate the depths to the water table, which is not the same as the depth to water in the wells because the water in some of the deeper wells is under considerable artesian head. The chemical composition and classification of such of these waters as were analyzed are shown on the pages facing those giving the general information concerning the same waters.

Data concerning wells and springs in Reese River basin and adjacent parts of Humboldt River basin, Nev.

General information.

Id.	Location.		Owner of well or name of spring.	Depth to water table. ^a Feet.	Diameter of well. Inches.	Yield of well. ^b Gallons per min.	Temperature of water. ° F.	Use of water.	Remarks.
	T.	N. R. E.							
1	33	43	Ames Spring.....	15	400	2	57	Stock.....	Artesian flow struck at about 300 feet.
2	33	45	Land Development Co.....	12	375	6	56	do.....	Do.
3	33	45	do.....	13	375	1		Domestic and stock.....	Artesian flow struck. See analysis.
4	33	45	do.....	13	375	1		Locomotives.....	Dug. 13 feet in diameter. See analysis.
5	33	47	Western Pacific R. R.....	6	10			Domestic.....	Dug. See analysis.
6	33	47	Dunphy estate.....	11	15		58	Cattle trains.....	Do.
7	33	48	Western Pacific R. R.....	14	20		53	Domestic.....	Do.
8	33	48	Dunphy estate.....	15	20			Domestic.....	Dug.
9	32	41	Summit Springs.....	12	15	3		Domestic.....	Do.
10	32	44	Tony Lonjero.....	12	15			do.....	Dug.
11	32	44	F. B. Starr.....	14	20			Domestic.....	Do.
12	32	44	Spring.....	12	15			Domestic.....	Do.
13	32	45	John Paul.....	12	400	5		Domestic and stock.....	Three wells. Artesian flows struck near bottom.
14	32	45	do.....	13	480			Locomotives.....	Slight artesian flow.
15	32	45	Southern Pacific Co.....	13	480			Domestic.....	Artesian flow struck near bottom.
16	32	45	Jenkins Bros.....	11	400	6	10	Domestic and stock.....	Three wells. Artesian flows. See analysis.
17	32	45	Land Development Co.....	12	300	6	10	Stock.....	Artesian flow.
18	32	45	do.....	15	300	6		Domestic and stock.....	Pumping plant.
19	32	45	do.....	13	60	6		do.....	Dug. See analysis.
20	32	45	James Blossom.....	12	15			do.....	Dug. See analysis.
21	32	45	Samuel Broyle.....	11	6	5		do.....	Two wells. Artesian flows.
22	32	45	Farris ranch.....	15	190	5	65	Stock.....	Artesian flow. See analysis.
23	32	45	do.....	12				Domestic.....	Dug.
24	31	43	Spring at Wilson ranch.....	78	83	25		Roadside watering.....	See analysis.
25	31	44	do.....					Stock.....	Dug.
26	31	45	Jenkins Martin ranch.....	12	500	6		Stock.....	Artesian flow. See analysis.
27	31	45	do.....	20	500	6		Domestic and stock.....	Two wells. Artesian flows.
28	31	45	Ramón Oyarbide.....	14	130	6		Domestic.....	Irrigation planned.
29	31	45	do.....	15	135	6		do.....	Do.
30	31	45	do.....	16	140	6		Pumping plant.....	Irrigation planned. See analysis.
31	31	45	Peale.....	12	34			Domestic.....	Dug. Pumping plant. Irrigation planned.
32	31	45	Charla ranch.....	74	77			Domestic and stock.....	Dug. Windmill. See analysis.
33	30	41	Blackfoot pump.....			5		Irrigation.....	See analysis.
34	30	42	"Blackfoot Well".....	7	10			Roadside watering.....	See analysis.

^a In wells with artesian head the water rises in the well above the level indicated.^b The yield given for flowing wells is the natural flow.

Chemical composition and classification of waters.

[Samples collected by G. A. Waring; analyzed by S. C. Dinsmore; parts per million except as otherwise designated.]

No.	Determined quantities.										Computed quantities ^a			Classification. ^a							
	Silica (SiO ₂)	Iron (Fe)	Cal- cium (Ca)	Mag- ne- sium (Mg)	Sodium and po- tassium (Na+K) ^b	Carbo- nate radicle (CO ₃)	Bicar- bonate radicle (HCO ₃)	Sul- phate radicle (SO ₄)	Chlo- ride radicle (Cl)	Ni- trate radicle (NO ₃)	Total dis- solved solids at 180° C.	Total hard- ness as CaCO ₃	Scale- form- ing in- gredients (s.)	Foam- ing in- gredients (l.)	Alkali coeff- icient (inches)	Mineral content.	Chem- ical char- acter.	Prob- ability of corro- sion. ^c	Quality for boiler use.	Quality for do- mestic use.	Qual- ity for irriga- tion.
4	73	Tr.	23	Tr.	47	38	76	24	6.0	0.0	250	58	140	130	19	Moderate	Na-CO ₃	N	Fair	Good	Good.
5	40	Tr.	54	18	55	0	259	49	46	0	426	209	236	150	34	do	Ca-CO ₃	N	Poor	Fair	Do.
6	50	0.05	72	Tr.	100	0	366	52	30	0	486	180	260	270	9.7	do	Na-CO ₃	N	do	do	Fair.
7	35	Tr.	48	13	75	9.6	275	59	35	0	429	173	200	200	17	do	do	N	Fair	do	Do.
8	47	Tr.	50	23	172	0	454	94	75	0	697	219	230	460	6.2	High	do	N	Very bad	do	Do.
17	40	Tr.	40	11	35	0	142	45	41	0	340	145	210	90	47	Moderate	Ca-CO ₃	(?)	Poor	Good	Good.
18	70	Tr.	30	7.0	50	0	183	32	14	0	300	104	160	140	21	do	Na-CO ₃	N	Fair	do	Do.
20	56	Tr.	30	1.0	50	0	162	30	17	0	298	79	160	140	21	do	do	N	do	do	Do.
22	65	Tr.	30	1.0	52	0	398	27	17	0	255	455	460	220	31	High	Ca-CO ₃	(?)	Bad	do	Do.
24	35	Tr.	123	36	82	0	44	67	28	0	750	452	120	120	57	Moderate	Ca-SO ₄	(?)	Fair	Good	Do.
26	20	Tr.	51	30	43	19	160	87	23	0	387	210	120	120	64	do	Ca-SO ₄	(?)	do	Fair	Do.
28	30	Tr.	70	31	77	29	120	187	66	80	624	302	280	210	27	High	Ca-SO ₄	C	Poor	Bad	Do.
32	25	Tr.	31	27	488	168	317	264	307	0	1,388	188	160	1,300	2.4	do	Na-Cl	N	Very bad	do	Poor.
34	23	Tr.	31	27	488	168	317	264	307	0	1,388	188	160	1,300	2.4	do	do	N	do	do	Do.

^a See standards for classification in U. S. Geol. Survey Water-Supply Paper 398, pp. 50-81, 1916.^b Calculated.^c C=corrosive; N=noncorrosive; (?)=corrosion uncertain or doubtful.^d Aluminum (Al), trace.

Data concerning wells and springs in Reese River basin and adjacent parts of Humboldt River basin, Nev.—Continued.

General information.

Sta.	Location.	Owner of well or name of spring.	Depth to water table, s	Depth of well.	Diameter of well.	Yield of wells	Temperature of water.	Use of water.	Remarks.
T. N. R. E.			Feet.	Feet.	Inches.	Gallons per min.	° F.		
35	30	— Lee.	8	10				Unused.	Dug.
36	30	do.	6	8				Stock.	Do.
37	30	Jack's home ranch.	35	60				Domestic and stock.	Dug. Windmill. See analysis.
38	29	Buckbrush Spring.	11	25	18	2		Domestic.	See analysis.
39	41	Indian ranch.						Irrigation.	Do.
40	29	Kane Springs.				10		Unused.	Dug. Small pumping plant. See analysis.
41	29	Hot Springs.	15	25		5	c 130	do.	
42	29	Childress Bros.	40	45		3	c 110	Domestic and stock.	
43	29	do.						Roadside watering.	
44	28	Mound Springs.						Railroad.	Dug. Abandoned.
45	27	Fish Creek ranch.	65	67				Irrigation.	Dug. See analysis.
46	27	Nevada Central R. R.	5	10		450	124	Domestic and irrigation.	See analysis.
47	27	Hot Springs.				50	122	Unused.	Do.
48	27	do.						Domestic.	Dug. See analysis.
49	26		24	25				Unused.	Do.
50	25	Cottonwood ranch.	24	27		10	102	Bathing.	Dug. Dry.
51	25	Nevada Central R. R.	81	81				Domestic.	Dug.
52	25	do.	20	22				Unused.	See analysis.
53	25	Cone Springs.						Domestic.	Dug. See analysis.
54	24	James Lister.	3	15	6			Bathing.	Do.
55	24	do.	6	10				Domestic.	Dug. Dry.
56	23	Phillippi.	11	210	6			Unused.	See analysis.
57	23	Nevada Central R. R.	6	10				Domestic.	Dug. See analysis.
58	22	Spring.						Railroad.	Artesian water stands in well 3 feet below surface.
59	22	do.						Stock.	Dug.
60	22	do.						do.	See Plate XI, B; also analysis.
61	22	Antelope Spring.						Unused.	Dug. See analysis.
62	22	Bradley Springs.						do.	Artesian water stands in well 3 feet below surface.
63	22	— Phillippi.	5	200	6			do.	Dug.
64	22	Watercress Springs.						do.	Artesian flow.
65	21	Spring.						do.	See analysis.
66	21	Malloy horse ranch.	6	18		1		Domestic.	Dug. See analysis.
67	21	Nevada Central R. R.	6	18				Railroad.	Dug.
68	20	Malloy upper ranch.	6	7				Domestic.	Do.
69	19	Spring.							

a In wells with artesian head the water rises in the well above the level indicated. b The yield given for flowing wells is the natural flow. c Maximum.

Chemical composition and classification of waters.

[Samples collected by G. A. Waring; analyzed by S. C. Dinsmore; parts per million except as otherwise designated.]

Determined quantities.												Computed quantities. ^a					Classification. ^c				
Silica (SiO ₂).	Iron (Fe).	Cal- cium (Ca).	Mag- ne- sium (Mg).	Sodium and po- tassium (Na+K). ^b	Carbo- nate radicle (CO ₃).	Bicar- bonate radicle (HCO ₃).	Sul- phate radicle (SO ₄).	Chlo- ride radicle (Cl).	Nit- rate radicle (NO ₃).	Total dis- solved solids at 18° C.	Total hard- ness as CaCO ₃ .	Scale- form- ing ingre- dients (s).	Foam- ing ingre- dients (f).	Alkali coeff- icient (inches).	Mineral content.	Chem- ical char- acter.	Prob- ability of corro- sion. ^c	Quality for boiler use.	Quality for do- mestic use.	Qual- ity for ir- riga- tion.	
37	22	0.10	125	20	85	0.0	400	100	67	64	675	394	420	230	26	High	Ca-CO ₃	{}	Poor	Bad	Good.
39	32	Tr.	75	14	38	0.0	212	34	84	0	413	245	280	100	24	Moderate	do	{}	do	Fair	Do.
41	117	Tr.	30	Tr.	327	0.0	761	109	34	0	1,032	75	210	880	2.5	High	Na-CO ₃	N	Very bad	do	Poor.
43	43	Tr.	104	25	109	0.0	346	172	78	32	735	362	360	290	21	do	Ca-CO ₃	{}	Poor	do	Good.
46	28	Tr.	40	10	100	0.0	251	48	72	0	428	141	160	270	12	Moderate	Na-CO ₃	N	Bad	Good	Fair.
47	41	Tr.	65	10	121	0.0	447	63	24	0	559	204	250	330	7.7	High	do	N	Poor	Fair	Do.
48	55	Tr.	64	Tr.	154	0.0	468	74	23	0	627	160	240	420	5.8	do	do	N	Very bad	do	Poor.
49	46	30	85	41	557	17	185	601	557	80	2,133	381	360	1,600	3.2	Very high	Na-Cl	{}	do	do	Do.
50	20	Tr.	80	12	52	0.0	251	33	49	64	455	249	280	140	30	Moderate	Ca-CO ₃	{}	Poor	Fair	Good.
54	42	Tr.	69	5.0	268	0.0	768	77	34	5.0	863	180	240	720	2.9	High	Na-CO ₃	N	Very bad	do	Poor.
55	41	Tr.	69	Tr.	280	0.0	763	74	34	6.0	905	172	240	760	2.8	do	do	N	do	do	Do.
60	67	Tr.	32	10	16	0.0	129	23	18	0	252	121	180	43	100	Moderate	Ca-CO ₃	{}	Fair	Good	Good.
66	57	Tr.	76	37	174	24	439	211	71	0	918	342	340	470	11	High	Na-CO ₃	N	Very bad	Bad	Fair.

^a See standards for classification in U. S. Geol. Survey Water-Supply Paper 393, pp. 50-81, 1916.^b Calculated.^c C=corrosive; N=noncorrosive; (?)=corrosion uncertain or doubtful.

Data concerning wells and springs in Reese River basin and adjacent parts of Humboldt River basin, Nev.—Continued.

General information.

Sta.	Location.		Owner of well or name of spring.	Depth to water table. ^a	Depth of well.	Diameter of well.	Yield of well. ^b	Temperature of water.	Use of water.	Remarks.
	T.	N. R. E.								
70	19	44	Spring.....	Feet.....	Feet.....	Inches.....	Gallons per min.....	° F.....	Supply for Austin.....	Piped to tank above town.
71	18	42	do.....	.....	.....	.....	100.....	52.....	Irrigation.....	Dug. See analysis.
72	18	42	Tony Gondolo.....	5.....	7.....	.....	.....	46.....	Domestic.....	Do.
73	18	42	Springs.....	.....	.....	.....	50.....	.....	Irrigation.....	Do.
74	18	42	Margaret Ryan.....	6.....	10.....	.....	.....	.....	Domestic.....	Do.
75	18	42	.....	7.....	8.....	.....	.....	.....	Unused.....	Dug.
76	18	43	Walsh home ranch.....	6.....	450.....	8.....	8.....	50.....	Stock.....	Artesian flow. See analysis.
77	18	43	W. S. Carter.....	30.....	505.....	6.....	6.....	.....	Unused.....	Artesian water rises within 7 feet of surface.
78	18	43	do.....	30.....	200.....	6.....	10.....	52.....	Domestic.....	Artesian flow. Irrigation planned. See analysis.
79	18	43	do.....	.....	25.....	.....	.....	.....	Irrigation.....	Dug. Dry.
80	18	43	Fred Ahlers.....	40.....	197.....	6.....	1.....	.....	Domestic.....	Artesian flow. See analysis.
81	18	43	do.....	40.....	110.....	6.....	.....	.....	Unused.....	Artesian water stands in well 2 feet below surface.
82	16	42	Walsh Hess ranch.....	15.....	20.....	.....	.....	.....	Domestic.....	Dug. Windmill. See analysis.
83	16	42	O'Toole ranch.....	80.....	108.....	.....	50.....	.....	Domestic and stock.....	Dug. See analysis.
84	15	41	J. J. Whaley (springs).....	.....	.....	.....	.....	.....	Irrigation.....	Do.
85	14	41	J. F. Bowler.....	11.....	15.....	.....	.....	.....	Domestic.....	Do.
86	13	40	Spring.....	.....	.....	.....	1.....	.....	Domestic.....	Do.
87	13	40	J. F. Schmalzing.....	12.....	20.....	.....	2.....	48.....	Domestic.....	Do.
88	13	42	Spring.....	.....	.....	.....	10.....	.....	Irrigates small garden.....	Do.
89	12	40	do.....	.....	.....	.....	.....	.....	Domestic and irrigation.....	See analysis.
90	11	40	O. C. Warner (spring).....	.....	.....	.....	75.....	63.....	Domestic and irrigation.....	Do.
91	11	40	Spring.....	40.....	.....	.....	1.....	.....	.....	Do.
92	11	40	do.....	.....	.....	.....	.....	.....	.....	Do.
93	11	40	do.....	.....	.....	.....	.....	.....	.....	Do.
94	11	40	do.....	.....	.....	.....	.....	.....	.....	Do.
95	11	40	do.....	.....	.....	.....	.....	.....	.....	Do.
96	11	40	do.....	.....	.....	.....	.....	.....	.....	Do.
97	11	40	Keough home ranch.....	6.....	10.....	.....	.....	.....	Domestic.....	Dug. See analysis.
98	11	40	Keough upper ranch.....	8.....	12.....	.....	.....	.....	do.....	Do.
99	10	40	Spring.....	.....	.....	.....	10.....	.....	Domestic.....	Do.

^a In wells with artesian head the water rises in the well above the level indicated.^b The yield given for flowing wells is the natural flow.

Chemical composition and classification of waters.

[Samples collected by G. A. Waring, analyzed by S. C. Dinmore; parts per million except as otherwise designated.]

No. of Pl. VIII.		Determined quantities.						Computed quantities. ^a					Classification. ^c									
		Silica (SiO ₂)	Iron (Fe)	Cal- cium (Ca)	Mag- ne- sium (Mg)	Sodium and po- tassium (Na+K) ^b	Carbo- nate radicle (CO ₃)	Bicar- bonate radicle (HCO ₃)	Sul- phate radicle (SO ₄)	Chlo- ride radicle (Cl)	Ni- trate radicle (NO ₃)	Total dis- solved solids at 180° C.	Total hard- ness as CaCO ₃	Scale- form- ing ingre- dients (g.)	Foam- ing ingre- dients (l.)	Alkali coef- ficient (inches)	Mineral content.	Chem- ical char- acter.	Prob- ability of corro- sion. ^c	Quality for boiler use.	Quality for do- mestic use.	Qual- ity for ir- riga- tion.
72	74	Tr.	75	67	42	66	14	417	109	17	0.0	590	360	340	180	48	High	Ca-CO ₃	N	Poor	Bad	Good.
76	87	Tr.	67	15	46	46	.0	310	40	23	.0	410	229	260	120	31	Moderate	do	N	do	Fair	Do.
76	22	Tr.	64	35	4.5	.0	.0	273	75	8.0	.0	369	304	270	12	290	do	do	{	do	do	Do.
78	17	Tr.	65	28	2.8	.0	.0	261	57	7.0	.0	345	277	260	8	290	do	do	{	do	do	Do.
80	33	Tr.	157	52	22	.0	.0	670	89	8.0	.0	694	606	580	60	160	High	do	{	do	do	Do.
82	44	Tr.	84	Tr.	23	12	.0	212	55	20	.0	366	210	290	90	79	Moderate	do	{	do	do	Do.
83	34	Tr.	64	10	62	.0	.0	237	64	17	64	468	201	270	170	23	do	do	{	do	do	Do.
85	67	Tr.	64	10	62	.0	.0	237	41	27	.0	368	185	210	110	45	do	do	N	do	do	Do.
87	39	0.02	51	14	41	.0	.0	205	21	10	.0	309	80	130	150	15	do	Na-CO ₃	N	Fair	Good	Fair.
90	60	Tr.	21	6.7	37	14	.0	146	22	16	6.0	261	112	180	100	30	do	Ca-CO ₃	N	do	do	Good.
98	48	Tr.	45	Tr.	57	14	.0	107	20	16	.0	281	120	180	110	24	do	do	N	do	do	Do.
	40	Tr.	48	Tr.	41	46	.0										do	do	N	do	do	Do.

^a See standards for classification in U. S. Geol. Survey Water-Supply Paper 398, pp. 50-51, 1916.^b Calculated.^c C=corrosive; N=noncorrosive; (?)=corrosion uncertain or doubtful.^d Aluminum (Al), trace.

GROUND WATER IN QUINCY VALLEY, WASHINGTON.

By A. T. SCHWENNESEN and O. E. MEINZER.

INTRODUCTION.

LOCATION AND AREA.

Quincy Valley is in Grant County, Wash., a little south and east of the center of the State (fig. 5). The lowland to which the term Quincy Valley is locally applied is not, however, a true valley in the usual sense of that word, for it is nearly as broad as it is long and is more appropriately called a basin. This basin is bounded on the north by the Badger Hills, on the south by the Frenchman Hills, on the west by Babcock Ridge and other low swells along the brink of the Columbia River gorge, and on the east by the high land east of Moses Lake. Its area is approximately 600 square miles.

The northern part of the basin is crossed by the transcontinental line of the Great Northern Railway; the eastern part is reached by branch lines of the Northern Pacific and Chicago, Milwaukee & St. Paul railways; and the region south of the Frenchman Hills is traversed by the main line of the Chicago, Milwaukee & St. Paul Railway, which can be reached without difficulty from the southern part of the basin by crossing the Frenchman Hills.

The principal towns in the basin are Ephrata and Quincy, both in its northern part, on the Great Northern Railway. Neppel is at the terminus of the branch line of the Chicago, Milwaukee & St. Paul Railway.

SCOPE OF INVESTIGATION.

For many years stockmen along Crab Creek have used the water from the stream to irrigate wild grass on the adjacent bottom lands, but within the last few years water has been pumped for irrigation in certain parts of the valley. Near Moses Lake some tracts are irrigated with water pumped from the lake but in other parts of the basin the water is pumped from wells. Most of the irrigated lands are in apple orchard, but a great variety of other crops, including alfalfa, corn, melons, vegetables, and small fruits, are raised by irrigation for home consumption and for the local market.

Repeated advances in the price of fuel for internal-combustion engines during the last few years has greatly increased the cost of irrigation. The burden has been especially heavy on irrigators who must pump the water from great depths and who are irrigating

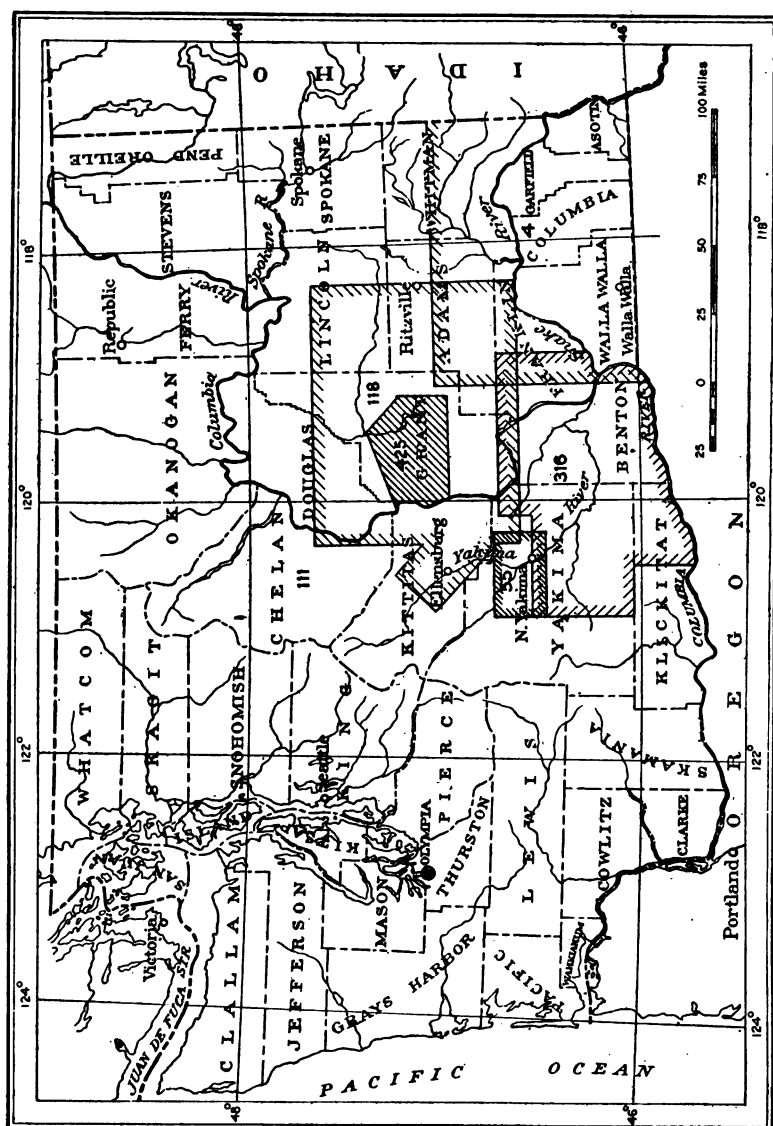


FIGURE 5.—Map of Washington showing location of Quincy Valley (shaded area) and other areas described in water-supply papers of the United States Geological Survey relating to ground water.

young orchards that are not yet bearing. In some orchards the trees have suffered through lack of water because of the inability of the owners to pay the fuel bills.

From time to time various projects for supplying the basin with water for irrigation have been considered. In 1909 Mr. Joseph

Jacobs made an investigation for the Quincy Valley Water Users' Association to discover the most practicable and economical source of water. In his report,¹ which was published by the Washington Geological Survey, Wenatchee River and Wenatchee Lake were considered the most feasible sources, and plans were made for a gravity system thus supplied, providing for the irrigation of 435,000 acres in Quincy Valley and in the region to the south, between the Frenchman Hills and Saddle Mountain. The estimated cost of the project was \$43,700,000, or approximately \$100 an acre. No means have yet been found for financing the project.

The residents of the basin have long looked to the near-by Columbia as a possible source of cheap electric power that could be used for pumping. It is pointed out that the rapids of the river afford power sites, that these rapids are now serious obstacles to navigation, and that in connection with the construction of works at the rapids to make them navigable provision could be made, at a proportionately small charge, for utilizing their power.

In 1909 and 1911 Army engineers made surveys of the Columbia from the mouth of Snake River to Wenatchee to determine the feasibility of such a combined project² but reported adversely on it, for the reason that the present and prospective commerce on the Columbia would not warrant the expenditure of that proportion of the total cost which would have to be charged against improvement of navigation. In view of the small amount of commerce to be benefited, it was concluded that the development of power should be considered the primary object and that the needs of navigation could be considered only incidentally.

If the project is considered solely as a means of obtaining power, the question at once arises whether the demand for power is sufficient to justify the undertaking. Neither the Federal Government nor private capitalists will undertake extensive power developments without the assurance of an adequate and certain market for the power. Irrigators in Quincy Valley recognize many advantages of electric power over power generated by internal-combustion engines, and if electric power had the additional advantage of cheapness it would doubtless almost completely replace that furnished by internal-combustion engines. The number of pumping plants and the resulting market for power will be determined by several factors, including topography, soil, and depth to water, but perhaps chiefly by the quantity of ground water obtainable. The importance of an adequate supply of ground water was recognized by the resi-

¹ Landes, Henry, Mangum, A. W., Benson, H. K., Saunders, E. J., and Jacobs, Joseph, A preliminary report on the Quincy Valley irrigation projects: Washington Geol. Survey Bull. 14, 1912.

² Kutz, C. W., 62d Cong., 2d sess., H. Doc. 693.

dents of the basin and it was the fundamental reason for their request for the investigation on which this report is based.

The material for the present report was collected by A. T. Schwennesen, who spent about two and one-half months in the field in the fall of 1916. During two weeks of this time Mr. Schwennesen was accompanied by O. E. Meinzer, and together they made a reconnaissance of the region adjacent to the basin. The report was written chiefly by Mr. Schwennesen, but Mr. Meinzer collaborated in certain parts. F. F. Henshaw, also of the Geological Survey, furnished valuable data and estimates on stream flow and evaporation in the region from 1910 to 1913, inclusive. The present preliminary report on the region will be followed by a full report containing the detailed data and maps.

ACKNOWLEDGMENTS.

The authors gratefully acknowledge the unfailing courtesy and willingness with which residents of the basin complied with requests for information, and are under obligations to the drillers for assistance in collecting well records. Special thanks are due Mr. Louis Mullerleile, of Quincy, who placed at the disposal of the Survey a large amount of material that he had collected relating to wells in the region.

TOPOGRAPHY.

TOPOGRAPHIC FEATURES OF CENTRAL WASHINGTON.

Quincy Valley is a part of the Walla Walla Plateau, which is the northern section of the Columbia Plateau province. The Walla Walla Plateau extends from the Cascade Mountains eastward to the Coeur d'Alene and Bitterroot mountains, and from the Colville Mountains and Okanogan highlands southward to the Blue Mountains in Oregon and Idaho, and to the basins of the Harney section in south-central Oregon. It consists essentially of great expanses of nearly level or gently sloping ground, interrupted by hills and by deep trenchlike valleys.

In general its surface conforms to the structure of the underlying basalt, being nearly level where the beds of basalt lie nearly horizontal, forming ridges where these beds have been upwarped into anticlines, and forming broad valleys where they have been downwarped into synclines. The canyons, locally known as coulees, are characteristic of the region. At many places they extend across the ridges, indicating that the streams by which they were formed existed before the ridges and persisted in their courses by cutting into the basalt beds when those beds were uplifted. The canyons of Columbia and Snake rivers and the large coulees which formerly contained

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rivers, such as Grand Coulee and Moses Coulee, are conspicuous examples of intensive stream trenching.

TOPOGRAPHIC FEATURES OF THE REGION AROUND QUINCY VALLEY.

The form of Quincy Valley and of the principal features that bound it are in accord with the relations existing between structure and surface forms throughout the Walla Walla Plateau. Structurally Quincy Valley is a broad, shallow basin, defined on the north by the fold that forms the Badger Hills, on the south by the arch of the Frenchman Hills, on the west by the monoclinical slope projected eastward from Table Mountain across the gorge of Columbia River, and on the east by a less obvious westerly dip of the rocks.

West of Quincy Valley is the gorge of Columbia River—a great trench cut into the resistant basalt to a depth of 800 feet and walled in many places by nearly vertical cliffs of basalt. The gorge is largely independent of the present structure, for it cuts squarely across such important east-west structural features as the Badger Hills and Frenchman Hills. Opposite Quincy Valley the gorge runs parallel to the general trend of Table Mountain. Here its course may have been controlled to some extent by the structure, but that the control was not complete is shown by the fact that the monoclinical eastward dip seen in Table Mountain is continued across the gorge.

The largest of the coulees in this region, and the one most closely related to the geologic history of Quincy Valley, is Grand Coulee. Opening from the canyon of the Columbia in the northeastern corner of Grant County, it extends southwestward 40 miles across the plateau to the northern margin of Quincy Valley. (See Pl. XIII.) Throughout the greater part of this distance it is a wide flat-bottomed canyon walled by cliffs of basalt. The bottom of the coulee contains a series of shallow lakes.

There is abundant evidence that the Grand Coulee is an abandoned channel of Columbia River. In the glacial epoch the northern part of the State was occupied by the Okanogan ice sheet and a lobe of that glacier extended across the canyon of Columbia River upon the Waterville Plateau. Deflected by this great ice dam, the waters of the Columbia flowed along the eastern face of the glacier, cut a deep gorge, formed a cataract 400 feet high just below the site of Coulee City, and, continuing southward, discharged into Quincy Valley. In this basin during at least the early part of the glacial epoch the waters carried by Grand Coulee formed a large lake, from which they were probably returned to the valley of Columbia River over cataracts at Frenchman Springs and the "Pot Holes" southwest of Quincy. Later they found an outlet, now occupied by lower Crab Creek, through the Frenchman Hills. This abandoned channel of

the Columbia was described by Symons¹ in 1882 and by Russell² in 1893; the abandoned cataract which it contained was seen by Russell, and both Symons and Russell made vague references to a very large Pleistocene lake, which Symons called Lake Lewis. The abandoned channel and cataract were also described by Calkins³ in 1905.

SURFACE OF THE BASIN.

ELEVATION.

The floor of Quincy Valley is a nearly smooth plain, which is highest along its northern and western borders and slopes gently toward the south and east. Most of the plain lies between 1,200 and 1,300 feet above sea level. The highest points are in Babcock Ridge, a smooth, gentle swell rising to an elevation of 1,600 feet, at the rim of the Columbia gorge; the lowest are in the sand-dune area south of Moses Lake, where the general elevation ranges from 950 to 1,000 feet.

DRAINAGE.

Crab Creek, the principal stream in Quincy Valley, rises in several branches in the vicinity of Davenport, Wash., at an elevation of about 2,500 feet. It flows at first southwestward and then westward as far as Adrian, whence it continues in a general southeasterly direction to the head of Parker Horn, a long, narrow arm of Moses Lake (see Pl. XIII); this stretch of the stream is known as upper Crab Creek. Along the greater part of the stretch above the mouth of Wilson Creek the flow is perennial; below Wilson Creek it is intermittent, the water sinking in some places and emerging from the gravel in others. During spring freshets there is a continuous flow, which for short periods may become very large.

Moses Lake is about 13 miles long and from one-half to three-fourths mile in average width. In 1916 the elevation of the water surface was 1,046 feet above sea level. The lake is comparatively shallow, the maximum depth as a rule not exceeding 35 feet.

From the west side of Moses Lake, about 2 miles north of its lower end, a shallow, meandering channel leads westward and then south-eastward across the sand-dune area. About 5 miles south of the lake this channel enters a coulee which cuts through the Frenchman Hills,

¹ Symons, T. W., Report of an examination of the upper Columbia River: 47th Cong., 1st sess., S. Ex. Doc. 186, 1882.

² Russell, I. C., A geological reconnaissance in central Washington; U. S. Geol. Survey Bull. 108, 1893.

³ Calkins, F. C., Geology and water resources of a portion of east-central Washington: U. S. Geol. Survey Water-Supply Paper 118, 1905.

and, continuing in a southerly direction to a point about 15 miles south of Moses Lake, it opens into a broad-bottomed, steep-walled canyon which extends westward along the north side of Saddle Mountain to Columbia River. This drainage course, through which the overflow from Moses Lake finds its way into the Columbia, is known as lower Crab Creek.

Lower Crab Creek receives contributions of water from the overflow of Moses Lake, from seepage of ground water, and in small amounts from several coulees that discharge into it from the east. In its lower course the water sinks and ordinarily no surface water is delivered to the Columbia.

Besides the surface water that enters Moses Lake by way of the channel opening into Parker Horn, considerable underflow enters the upper part of the lake or emerges as a large spring at the head of Rocky Ford Creek, which discharges into the lake.

In the western part of the basin a narrow belt of country contiguous to the gorge of the Columbia drains westward toward the river. This drainage reaches the river through a number of small gullies that head a short distance out on the plain and lead to cuts in the basalt rim rock. The gullies are dry except during rapid thaws or periods of heavy rain.

Large areas in the central and southern parts of the basin are covered by deposits formed by the wind. In these areas the gentle slopes, the porous soil, and the constant shifting of the sand prevent the establishment of any permanent drainage system. The precipitation on these surfaces either sinks into the soil immediately or gathers in undrained hollows which have been scooped out by the wind and from which it escapes by seepage or evaporation.

FEATURES PRODUCED BY WIND.

The agent which at present is most active in modifying the surface of the basin is the wind. In the northern and western parts of the basin the wind has effected only slight changes in the shape of the surface, but the results of wind work are abundantly shown in the sand drifts along the fences bordering the roads, where the soil has been stirred up by traffic, and in the sand ripples in the plowed fields. In the sandy areas of the central and southern parts of the basin the effects of wind work are more pronounced, and are most conspicuous in the sand-dune area south and southwest of Moses Lake, where the surface is thickly covered with sand dunes interspersed with undrained depressions. Many of the dunes are 40 to 50 feet high and one-fourth to one-half mile long, and in places chains of dunes extend for miles across the area.

Where the sand for building the dunes has been excavated by the wind, there are shallow undrained basins, most of which are elliptical and which range in area from a few acres to more than 100 acres. In that part of the sand-dune area locally known as the "Pot Holes" many of these basins contain ponds of water bordered by narrow strips of meadow. Because of constant evaporation from the ponds the water is somewhat alkaline and the surrounding meadows are covered by a thick growth of salt grass and by alkali crusts. Tules and other water-loving plants grow in the ponds, and willows are common on the lee side of the dunes adjacent to the ponds.

In the sand-dune area the drainage courses have been greatly changed by the shifting sands. Thus Moses Lake owes its origin to the damming of Crab Creek by wind-blown sand.

FEATURES PRODUCED BY STREAMS.

The topography of the eastern part of the basin on both sides of Moses Lake, from Ephrata and Soap Lake to the sand-dune area, is largely the result of stream work. During the glacial epoch a great mass of gravel was discharged from the mouth of Grand Coulee and was spread in a sheet over the eastern part of Quincy Valley, completely obliterating the preexistent drainage lines and surface irregularities. As the glacial floods subsided the streams cut into the material thus laid down, and, with variations in the amount of run-off and temporary halts in the down-cutting process, produced gravel terraces separated by wide, flat-bottomed channels by which the present drainage is largely determined. Hiawatha Valley and Ephrata Valley are ancient stream valleys of this kind. Moses Lake occupies a similar ancient stream channel which was modified by wind-blown sand. From the water's edge steep banks rise abruptly to gravel terraces which occur at various heights up to 100 feet above the lake.

CLIMATE.

The "Big Bend country," embracing Douglas, Grant, Lincoln, and Adams counties, is recognized as the most arid part of the State of Washington. The average annual precipitation in this region, so far as the records show, ranges from 7 inches in the southern part to about 14 inches in the northern part. Temperatures exceeding 100° above zero in summer and 15° below zero in winter are not unusual, but owing to the dryness of the air the summer heat is seldom very oppressive and the cold of winter causes less suffering than in a more humid climate.

Summarized data regarding precipitation in Quincy Valley and the surrounding region are presented in the following table:

Mean monthly and annual precipitation, in inches, in Quincy Valley and adjacent region.

Station.	Elevation above sea level.	Length of record.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	<i>Feet.</i>	<i>Years.</i>													
Waterville.....	2,624	a 27	1.67	1.39	0.96	0.79	1.26	0.93	0.47	0.05	0.55	0.77	1.63	1.92	12.84
Wilbur.....	2,203	b 20	1.78	1.31	.78	.79	1.62	1.07	.57	.58	.62	1.10	1.86	1.67	13.75
Ritzville.....	1,825	c 18	1.28	1.39	.80	.56	.94	.69	.27	.26	.47	.64	1.61	1.62	10.53
Ephrata.....	1,265	d 10	.96	.68	.54	.29	.78	.86	.25	.70	.47	.77	.75	.92	7.97
McConihe.....	1,072	e 6	.82	.75	.33	.38	.59	.61	.37	.44	.19	.90	1.10	.88	7.36
Trinidad.....	900	f 8	1.63	1.15	.52	.33	.55	.66	.29	.15	.44	.52	1.39	1.32	8.95
Wahluke.....	410	g 13	1.17	.75	.51	.24	.45	.54	.33	.37	.25	.69	.93	.89	7.12

a Partial records for years 1890, 1892, 1908, 1909, 1910, 1911, 1913, 1914, and 1916 included.

b Partial records for years 1892, 1898, 1899, 1900, 1907, 1908, and 1916 included. No record for years 1893 to 1897.

c Partial records for years 1899, 1900, 1902, 1903, 1905, 1906, 1907, and 1910 to 1916 included.

d Partial records for years 1903, 1905, and 1907 to 1912. No records for years 1913 to 1916.

e Partial record for 1916.

f Partial records for years 1909 and 1916.

g Partial records for years 1904, 1911, 1913, and 1916.

The mean annual precipitation in Quincy Valley, according to the records from Ephrata and McConihe,¹ is between 7 and 8 inches. In the region north and east of the basin the precipitation increases with increase in elevation, as is shown by the table.

Much of the winter precipitation is snow, which usually remains on the ground only a few weeks after each fall, but as it generally comes in periods of severe cold it forms a protective blanket that prevents plants from freezing. In melting it supplies moisture slowly enough to be absorbed by the fine deep soils of parts of the valley.

Because of the lower elevation of Quincy Valley, the winters are somewhat milder than in most parts of the adjacent region, and the frost-free season is longer. This is an important factor in the growing of fruit. The large number of clear sunny days is also an important factor in the ripening and coloring of fruits in this region.²

SOIL AND VEGETATION.

Before 1900 practically the only settlers in the basin were a few stockmen who had selected lands along Crab Creek and Moses Lake, chiefly because of the ready water supply, but also because of the good pasturage on the Crab Creek bottoms and among the sand dunes south of Moses Lake.

After 1900, other settlers, favorably impressed with the soil and general aspect of the country and influenced by the success of wheat farmers on the Waterville Plateau to the north, came into Quincy Valley to raise wheat. Most of the early wheat growers settled in the northwestern part of the basin where the conditions for raising wheat are the most favorable, and as some of the first crops were

¹ McConihe is a station near the head of Moses Lake (sec. 28, T. 20 N., R. 27 E.).

² Saunders, E. J., Soil survey of Quincy area: U. S. Dept. Agr. Bur. Soils Field Operations, 1911, p. 12.

exceptionally good, Quincy Valley was heralded as a newly discovered wheat region. The result was a great influx of settlers into all parts of the basin and within a few years practically all the public land was taken as homesteads.

At present (1917) only the lands in the vicinity of Quincy, on Babcock Ridge west of Quincy, and in the region extending southward from Quincy, are used regularly for growing wheat. In a season of average rainfall the wheat crop averages about 8 to 10 bushels per acre,¹ and in exceptionally favorable seasons 25 to 30 bushels per acre has been reported. Because of the higher elevation and somewhat greater precipitation the wheat lands on Babcock Ridge yield the best crops.

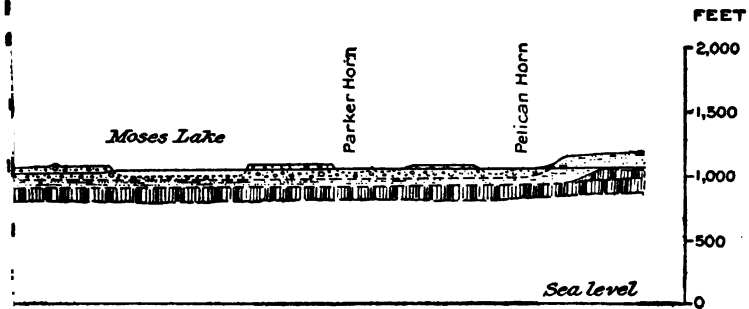
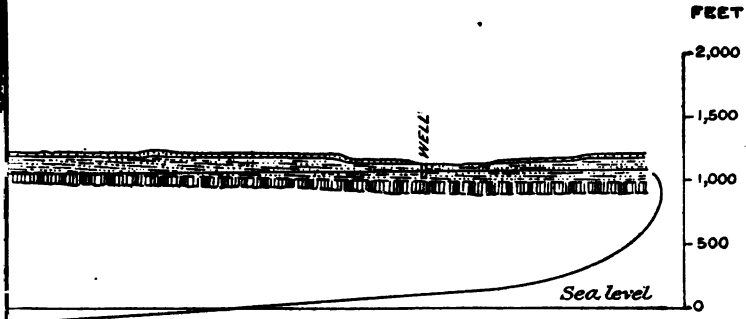
But the lands in a large part of the basin proved unsuitable for raising wheat, and many of the settlers, discouraged by repeated crop failures, abandoned their claims or stayed only long enough to obtain title. Some tracts which would not produce wheat were found, however, to yield fair crops of plants more resistant to drought, such as rye, corn, and Sudan grass. In most seasons these crops do not mature sufficiently to produce marketable grain, but they make good winter feed, which is sometimes sold locally but is more often fed to the stock on the farm. Thus by feeding the farm products and utilizing the open range, or, in other words, combining farming with stock raising on a small scale, many of the settlers have managed to get along very well.

Large tracts, including the region covered by drifting sand, chiefly in the southern part of the basin, and the stony areas in the northeastern part, are entirely uncultivated, for many original settlers on these lands soon found them worthless without irrigation and consequently abandoned most of them. The uncultivated areas are used for grazing by resident stockmen and by sheepmen who are forced to bring their flocks out of the mountains at the beginning of winter. Except for short periods during the winter, when deep snow is on the ground, cattle and sheep subsist on the native sagebrush and bunch grass. Four or five weeks of feeding, in the aggregate, usually suffice to carry stock through the winter. Rye hay, corn fodder, alfalfa hay, Sudan grass, and straw are generally used for winter feeding.

The report on Quincy Valley by Mangum, Van Duyne, and Westover,¹ published by the United States Department of Agriculture, contains a full discussion of the various types of soil in the valley and their value for agriculture, and includes also a detailed map showing the areas covered by the soils of various types.

¹ Mangum, A. W., Van Duyne, Cornelius, and Westover, H. L., Soil survey of the Quincy area, Wash.: U. S. Dept. Agr. Bur. Soils Field Operations, 1911 (Advance sheets), p. 17, 1918.

WATER-SUPPLY PAPER 425 PLATE XIV



GEOLOGY.

GENERAL FEATURES.

Quincy Valley lies within the vast area which in Miocene time was inundated by great floods of basaltic lava. Though covered in most places by sedimentary deposits, the basalt nowhere in the basin is very far beneath the surface. The great thickness of the basalt series is well shown in the gorge of the Columbia, which has been cut into the basalt to a depth exceeding 800 feet without exposing the underlying rocks.

The sedimentary deposits overlying the basalt consist of unconsolidated beds of clay, sand, and gravel derived from the Okanogan glacier, which occupied the Waterville Plateau in the Pleistocene epoch and discharged its débris-laden floods into Quincy Valley through the Grand Coulee. (See Pl. XIII.) Some of these deposits were laid down in the quiet waters of a lake; others were laid down by streams. Overlying the basalt, the lake beds, and, in some places, the stream deposits is a mantle of wind-blown sand and silt. (See fig. 6 and geologic section, Pl. XIV.)

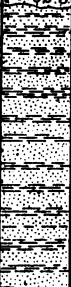
System.	Series.	Formation.	Section.	Thickness in feet.	Character of formation.	Character of topography and soil.
Quaternary.	Recent.	Wind-blown deposits.		50	Wind-blown silt and sand.	Level plains and sand dunes. Soil ranging from silty loam to dune sand.
		Unconformity.				
	Pleistocene.	Glacial-outwash deposits.		90	Stratified sand, gravel, and boulders.	Terraces and broad, shallow channels. Gravelly soil.
		Unconformity.				
Tertiary.	Miocene.	Lake beds.		300	Stratified clay and sand with local beds of gravel and boulders.	No natural exposures except in a few places on the faces of terraces and in small areas where soil has been removed by winds.
		Unconformity.				
		Yakima basalt.		1,300±	Basalt with a few thin beds of tuff.	Rough, broken areas and precipitous cliffs.

FIGURE 6.—Generalized columnar section of geologic formations in Quincy Valley, Wash. 74351°—19—wsp 425—10

YAKIMA BASALT.¹

The basalt of Quincy Valley, in its typical development, is a hard, dense, fine-grained rock, varying in color from dark gray to black, except on weathered surfaces, where it is usually brownish. The lava that formed the basalt was not all poured out at one time but was a series of flows, and each bed represents a distinct extrusion. The texture of the basalt shows considerable variation. At the upper surface of a bed the rock is usually scoriaceous, or "honeycombed," because of the expansion and escape of the dissolved gases in the lava, but the rock becomes increasingly dense toward the interior of the flow.

By the characteristic "honeycombed" structure the individual lava flows can be identified, and different flows can be distinguished from one another. In the gorge of the Columbia, where the basalt underlying Quincy Valley is exposed, six or eight different flows can be identified. The individual beds are usually not more than 50 to 150 feet thick, but their lateral extent is great, for their edges may be traced for miles along the canyon walls without any evidence of thinning out. At a few places thin beds of tuff, or volcanic ash, are interbedded with the massive basalt, but their volume is insignificant in comparison with the great volume of the basalt.

A characteristic and almost universal feature of the basalt is the system of joints perpendicular to the bedding planes, by which the sheets are broken into prismatic columns as a result of contraction in the process of cooling. This columnar jointing is splendidly displayed in the palisades of the Columbia gorge and the great coulees.

Structurally Quincy Valley is a shallow basin. At the rim of the Columbia gorge the beds of basalt dip eastward at an angle of 1° or 2°. Farther east the beds gradually flatten out and then rise again with a gentle inclination east of the valley. To the north the beds rise rather steeply to the Badger Hills, and to the south they are upturned to form the Frenchman Hills. The dips do not represent the original position of the beds but are due chiefly to gentle warping at some time since the deposition of the basalt.

Normally the basalt is compact and contains almost no pores capable of transmitting water. The ability of the basalt to absorb and store large quantities of water is due to the zones of porous rock between the successive beds and to the joints by which the beds are broken. Although the porous contact zones are generally thin and irregular, in many places they are thick, and, in connection with communicating passages produced by vertical and horizontal joints,

¹ This name was first used by Geo. Otis Smith in Water-Supply Paper 55 to differentiate the basalt of Miocene age from the older and younger basalt formations included in the general term Columbia River lava as used by I. C. Russell. F. C. Calkins, in Water-Supply Paper 118, mapped the basalt of Quincy Valley as Yakima basalt, and later maps correlate the basalt of this area with the typical Yakima basalt.

they form a circulating system through which water may travel for long distances.

LAKE BEDS.

CHARACTER AND DISTRIBUTION.

Lying upon the surface of the basalt are sedimentary deposits consisting of a series of stratified clay, sand, and gravel, which there is good reason to believe were laid down in impounded waters. The deposits are rarely exposed at the surface but are shown by well records to be widely distributed and continuous over nearly all parts of Quincy Valley. In the western, central, and southern parts of the basin the formation is covered by wind-deposited soils and drifting sands, and in the eastern part by glacial gravel. (See geologic section, Pl. XIV.)

Along the rim of the Columbia gorge the lake beds are absent and the basalt outcrops at the surface. In most of the western and north-western parts of the valley they are not more than 30 to 40 feet thick, but they thicken eastward, and wells on Morrison Flat penetrate nearly 300 feet without reaching the basalt. In the eastern part of the basin the upper 150 to 200 feet of the series has been removed by stream erosion and replaced by a thick covering of glacial stream deposits.

No complete section of the lake beds is exposed anywhere in the area, but as encountered in wells the beds consist of a series of alternating beds of clay, silt, and sand, and occasionally a layer of gravel. The clays are light gray, greenish gray, blue, or black, and are generally heavy and compact, but are in places of light weight and open texture because of an admixture of volcanic ash. Some of the dark-colored clays contain large amounts of organic matter, a fact that probably accounts for the foul odor and gas reported from some wells that penetrate the clays. Petrified wood and bones and fossil shells are found in the clays. The coarser materials of the lake deposits are of all grades, ranging from light-colored silt and very fine sand to beds of coarse boulders.

ORIGIN AND AGE.

The topography of the basin, the regular stratification of the sediments, the presence of fossils, and the widespread occurrence of erratic boulders are evidences that the valley was at one time occupied by a lake. This subject will be more fully discussed in the final report. To create a lake in the valley at the present time all that would be necessary, providing the run-off were sufficient, would be to block the gap where lower Crab Creek passes through the Frenchman Hills.

W. H. Dall states that the fossils collected from the lake beds are fresh-water species, all of which are still living and are not older than the Quaternary period. They are of the boreal type and could have lived in the cold water of a glacial lake.

GLACIAL OUTWASH.

DISTRIBUTION AND CHARACTER.

Deposits of glacial outwash cover a large area extending from the mouth of Grand Coulee, past Ephrata, and southward into the Moses Lake region and Hiawatha Valley. They consist mostly of fragments of basalt, but other rocks, chiefly granite, are sparsely represented. The materials are fairly well assorted, ranging in coarseness from sand to large boulders.

Near Soap Lake and Ephrata these deposits lie directly on the basalt, but farther south, in the vicinity of Moses Lake and in Hiawatha Valley, they lie on the lake beds. Having been deposited on an uneven surface, the formation varies in thickness from place to place; its greatest known thickness, as shown by well records, is about 90 feet.

ORIGIN AND AGE.

The outwash deposits were derived from the same source as the lake beds—that is, they were laid down by the *débris*-laden floods that were discharged through Grand Coulee from the Okanogan glacier in the Pleistocene epoch. Most of the material forming the higher terraces near the mouth of Grand Coulee was probably deposited at the same time that the fine sediments were being laid down in the glacial lake. The sudden lessening of the velocity of the flood waters as they emerged from Grand Coulee and spread out over the plain and the consequent decrease in their carrying power caused the coarse material to be deposited near the mouth of the canyon while the finer sediments were carried into the lake.

The lowering of the lake outlet did not cease with the draining of the lake but continued below the floor of the lake, the result being that in the eastern part of the basin the upper part of the lake beds and much of the previously deposited outwash material was removed, and the general level of this part of the valley was reduced. Later more outwash material was deposited on the eroded surface and the region was built up to its present general level. Neither deposition nor erosion, however, was continuous, for the glacial streams alternately cut channels and then refilled them with gravel, and these successive episodes are recorded in the terraces of the region.

WIND-BLOWN DEPOSITS.

Overlying the basalt, the lake beds, and, in some places, the glacial outwash deposits, is a thin mantle of wind-blown material consisting of fragments ranging in size from very fine silt to coarse sand. Except for the gravelly soils of the eastern part of the basin and the residual soils in the areas of outcropping basalt along the edge of the Columbia gorge, practically all the soils of the basin are composed of wind-blown materials, which also extend beyond the boundaries of the basin and cover the Frenchman Hills and the plain south of the hills. North of the basin wind-blown soils are found on the Badger Hills and the Waterville plateau. The wind-blown deposits of Quincy Valley are derived from the fine sediments deposited in the glacial lake. Under the prevailing arid climate these dry, loose-textured materials, only slightly protected by the meager vegetation, are easily moved about by the high winds, which at certain times of the year occur with great frequency. In the western part of the basin, where the soils are of very fine texture, the winds have produced only minor irregularities of the surface, but farther east, where the sands are coarser, the effect of the wind is much more conspicuous, and sand dunes are familiar features.

WATER TABLE.**DEPTH TO WATER.**

The depth to water in Quincy Valley was ascertained at about 250 widely distributed points, at most of which it was accurately measured in wells. Where measurement was not possible, reports were obtained from well owners, drillers, and other reliable persons. In general the depth to water varies with the elevation of the land surface, the water being nearest the surface in the low areas and the depth increasing progressively with increase in altitude.

In a part of the sand-dune area southwest of Moses Lake the ground water comes to the surface in many springs and collects in depressions among the dunes, forming small ponds and marshy tracts. Extending northward from this area to the vicinity of Mae and westward along the foot of the Frenchman Hills to a point nearly 20 miles west of Crab Creek, and including a large part of the dune area, is an extensive region in which water is less than 50 feet below the surface. Smaller areas outside of the dune area in which the ground water is within 50 feet of the surface include a part of Hiawatha Valley, the lowest terraces bordering Moses Lake, the bottom lands along Rocky Ford Creek, and strips of land on both sides of upper Crab Creek in its lower course, where it is locally known as Willow Creek.

The depth to water ranges from 50 to 100 feet throughout much of the sandy country in the south-central part of the basin, including the district near Bailey and that south of Morrison Flat. Other areas where the depth to water ranges between 50 and 100 feet include most of Hiawatha Valley, terraces of intermediate height in the vicinity of Moses Lake, and the lower terraces around Ephrata, Soap Lake, and Adrian.

The depth to water ranges from 100 to 150 feet in a large area in the west-central part of the basin extending westward from Morrison Flat and northward from Low Gap almost to Winchester. Other areas where water is found at these depths include the highest terraces in the Moses Lake region, the highest parts of the interstream areas extending from Ephrata to the vicinity of Moses Lake, and large parts of the upland surface east of Moses Lake and upper Crab Creek.

The depth to water is 150 to 200 feet throughout Morrison Flat, south of the Great Northern Railway, in the immediate vicinity of Winchester, and in a belt about 4 miles wide extending from Winchester to Burke.

FORM OF THE WATER TABLE.

Near Quincy, in most of the area south and west of Quincy, and in a belt north of the railroad near Winchester the depth to water ranges from 150 to 300 feet.

The position of the water table, or upper surface of the zone of saturation, is shown with respect to sea level by contours on Plate XIII. West of the steep slope that extends along the east side of Morrison Flat from within 4 or 5 miles of Ephrata almost to the Frenchman Hills the water table is nearly level or only slightly inclined, except along the north edge of the basin, where it rises toward the Badger Hills, and along the west edge, where it drops abruptly in the direction of the Columbia gorge. The elevation of the water table throughout this area, according to accurate determinations made at a large number of points, is about 1,080 feet above sea level. East of this steep slope the water table descends rapidly to a minimum level of about 1,000 feet above the sea.

In the eastern province the water table descends at a fairly uniform rate from the north to Moses Lake (altitude, 1,046 feet) with the surface of which it coincides. On the west side of the south part of Moses Lake the water table descends abruptly from the lake level to an elevation of only 1,030 feet above sea level in Hiawatha Valley and the vicinity of Mae. Thence, it declines more gradually southward to a level of about 1,000 feet in the sand-dune area, where it comes to the surface in many places and coincides with the surfaces of the ponds.

WATER-BEARING FORMATIONS.**WATER IN BASALT.**

The basalt underlying Quincy Valley consists of a series of beds, each of which represents a separate flow. The upper crust of a lava sheet generally has a vesicular or "honeycombed" structure, caused by the escape of steam and other gases from the molten lava, and its upper surface is generally rough and broken, owing to sudden chilling of the lava. Consequently many openings, some of which are extensive, occur between the successive beds, and these are capable of holding much water. In some places the successive beds are separated by beds of tuff and other volcanic fragmental material, but these interbedded deposits are of small volume and almost impervious, and consequently furnish little storage space for water. The interior of a bed, formed of a lava that cooled gradually, is usually fine grained and compact, but in the process of cooling there was much contraction, so that joints and fissures which provide for the storage and circulation of water were formed throughout the mass. The total capacity of the basalt formation for water is therefore rather large.

In the western part of the basin, including the region around Quincy, Burke, and Winchester, and north of the railroad between Winchester and Ephrata, almost all the wells obtain their water from the basalt. Near Quincy and Winchester large supplies are obtained for irrigation. A number of wells yield between 250 and 500 gallons per minute and one well near Quincy produces between 900 and 1,000 gallons per minute under continuous pumping. Near the rim of the Columbia gorge some wells have failed to obtain adequate supplies, but throughout the rest of the region failures are rare. Most of the large yields of water are obtained from beds of the "honeycombed" texture found between layers of compact material. A few of them come from the massive basalt.

The water in the basalt is derived from that which falls on the basin and percolates downward and from that which has been absorbed by the basalt outside of the basin and has traveled laterally underground perhaps for a long distance. In the western part of the basin, where the materials overlying the basalt are dry, most of the water that falls as rain or snow does not get far below the surface. This statement is especially true of the precipitation in the areas overlain by fine silty soils. Where the basalt is at or near the surface or where the sediments above the basalt consist of gravel or coarse sand the precipitated water sinks more rapidly below the reach of evaporation and transpiration, and a larger proportion reaches the water table. The numerous undrained basins are also favorable to

intake of water. If the average annual precipitation over an area of 300 square miles in the western and central parts of the basin west of the sag in the water table shown in Plate XIII is $7\frac{1}{2}$ inches, and 10 per cent of this precipitation reaches the water table, the average annual underground supply from this source is about 12,000 acre-feet.

The structure of Quincy Valley, determined by the lava beds that dip toward it from all directions, is favorable for the accumulation of ground water under the basin, but, on the other hand, the gorge of the Columbia, and, to a less extent, Moses Coulee and other deep coulees, are very unfavorable.

The map (Pl. XIII) shows that the water table is highest along the northern border of the basin. As water underground, like water at the surface, is highest near its source, this map indicates that one of the main sources of supply is the plateau north of the basin. The basalt beds out of which the plateau is built dip southward, and water which falls on the plateau may be led down the dipping strata beneath Quincy Valley. The plateau lies considerably higher than the basin and receives more abundant precipitation. As it is a surface of extensive erosion in which porous beds of the basalt formation are exposed, much of the rain and snow which it receives may be absorbed by the rocks.

Some parts of the plateau are, however, so deeply dissected as to diminish its efficacy as an intake area. Lynch, Moses, and Grand coulees (see Pl. XIII) are cut many hundreds of feet into the basalt, and the porous beds are exposed to leakage along the walls of the coulees. Where the coulees cut the water-bearing beds that underlie Quincy Valley and extend down to the level of the water table beneath the basin they effectively bar the movement of ground water into the basin and constitute definite outer limits for the areas contributing ground water. The contributory area on the north is therefore limited by Lynch, Moses, and Grand coulees, but between Moses Coulee and Grand Coulee there is no impassable barrier to the migration of ground water. (See Pl. XIII.)

That there is not very ready movement through the basalt laterally is indicated by the nearly level position of the water table over the greater part of the basin and by its abrupt downward slope, especially on the west side of this level area. The contributory area on the north probably does not include more than 300 square miles. The average annual precipitation on this area is about 15 inches. If 5 per cent of this precipitation is absorbed and migrates to Quincy Valley, the annual contribution is about 12,000 acre-feet.

West of Quincy Valley the gorge of Columbia River extends far below the level of the water table of the deepest water-bearing bed that has been reached by wells in the basin. There is therefore no contribution from the west. The loss of water from the basalt beds

at the outcrops is, however, not so great as might be expected, as is shown by the form of the water table (Pl. XIII), by the large yields of wells situated within a few miles of the gorge of Columbia River, and by the scarcity of large springs along the gorge. The retention of the water in the reservoirs of basalt is probably due both to the eastward dip of the beds and to a general lack of lateral communication between the cavities in the basalt.

There is an erroneous belief among some of the inhabitants of Quincy Valley that the water in the basalt comes from Lake Chelan, because the water table throughout most of the western and central parts of the basin stands at practically the same level as the lake—about 1,080 feet above sea level. It is obvious that no water can be derived from this source because of the existence of the intervening Columbia gorge, which is cut several hundred feet below the level of the lake, and below the water table of Quincy Valley, and is also cut through the water-bearing beds tapped by the wells in the basin.

That no large supply is received from the region south of Quincy Valley is shown by the water levels in the southern part of the basin and by the structure and topography of the region to the south. The northern limb of the anticline that forms the Frenchman Hills is narrow and the area south of these hills is deeply dissected.

East of Quincy Valley is an extensive area that slopes toward the basin and is underlain by beds of basalt that dip toward and extend beneath the basin. These beds no doubt deliver water in the general direction of the basin. On account of the sag in the surface and in the water table in the eastern part of the basin (Pl. XIII) this water probably does not reach the central and western parts of the basin but leaks into the sediments that overlie the basalt in the eastern part. If the more impervious beds of the basalt formation are sufficiently competent as confining beds, some of the water in the underlying porous beds may be carried by artesian pressure to the central and western parts of the basin, but there is considerable evidence that such artesian movement is absent or unimportant.

It appears, therefore, that most of the water in the basalt in the western and central parts of the basin is derived from rain and snow that fall there or on the upland farther north.

In the western part of the basin artesian pressure that will lift the water in deep wells much above the water table is not to be expected because of the depressing influence of the gorge of Columbia River. In the low area adjacent to Crab Creek and Moses Lake, where the water table sags (see Pl. XIII), the water from deep basalt beds would probably rise farther above the level of the water table, and it is possible that the artesian pressure would be sufficient to bring the water to the surface in the lowest places.

That the quantity of water stored in the basalt beneath the basin is large and that there is considerable underground circulation is shown by the fact that single wells yield 250 to 1,000 gallons a minute without diminution in the supply great enough to have been detected. The amount of water stored beneath the basin is, however, not a safe criterion by which to gage possible development of irrigation, for it may have taken centuries for this water to accumulate and the rate of inflow may be very slow. In considering the amount of water available for irrigation the quantity now stored in the rocks is not so important as the annual increment to the supply. It is evident that even though much water is stored beneath the basin, continual withdrawals in excess of replenishment will result in a gradual lowering of the water table.

Before any water was pumped there was probably a natural balance between loss and gain, the leakage out of the basalt in Quincy Valley being about equal to the intake, and leakage will continue in spite of recoveries by pumping. Therefore, even if the average annual intake is as much as 24,000 acre-feet, the supply that will be available year by year is less than this amount, although by pumping out the water now in storage a much larger quantity could be obtained for a few years.

Whether the water table has been lowered by the pumping that has already been done is not precisely known. The numerous exact measurements of depths to water that have been made in connection with the present investigation, will, however, make it possible to determine very closely the effects of future pumping operations.

The conclusions regarding the water in the basalt underlying Quincy Valley may be briefly stated as follows: The quantity of water stored in the basalt is large. The conditions are such that it is impossible to estimate closely the annual intake or the amount that can be recovered annually by pumping, without drawing seriously on the reserve, but the authors believe that the annual intake of water is not more than 24,000 acre-feet, and that the quantity which can safely be pumped annually within the area in which the wells end in basalt is less than this amount. The available supply is doubtless adequate to serve indefinitely the land now under irrigation, and experience may prove that considerably more land can be brought under irrigation. The geologic and topographic conditions make it certain, however, that it will be impossible to irrigate the entire basin with water obtained from this source, or even a large proportion of the area in which the wells end in basalt, and they also indicate that it would be unwise at present to increase the area to be irrigated with the water from the basalt by more than a few thousand acres.

WATER IN LAKE BEDS.

Throughout the central part of the basin—on Morrison Flat and adjacent areas to the north and west and in the sandy country extending southward from Morrison Flat to the Frenchman Hills and southwestward to Bailey and Low Gap—most of the wells obtain water from the unconsolidated, fine-grained, lake beds that overlie the basalt. The material penetrated in wells in this part of the basin consists of clay and sand in alternating beds, and a few thin layers described as “lime rock” or “hardpan.” Beneath these deposits basalt is found at depths ranging from less than 100 to more than 350 feet in different localities. Beds of quicksand, coarse basaltic sand, and occasionally of fine gravel that yield good supplies of water are found at intervals below the water table.

Many wells have been sunk into the lake beds, and, in so far as information was obtained, none of them have failed to get water, although a number of owners of comparatively shallow stock or domestic wells have reported “small” or “insufficient” yields. Wells that are properly constructed and are sunk deep enough to penetrate several water-bearing beds generally fulfill all requirements. Pumping plants supplying water for irrigation have been installed on Morrison Flat and in a number of other places, and single wells have been reported to yield 300 gallons per minute.

In the lake-beds area the water table is at about the same elevation as in the basalt area to the west and distinctly higher than in the area of glacial outwash to the east. It appears, therefore, that the water in the lake beds is derived from the same sources as that in the basalt and is not supplied to any important extent by Crab Creek or the glacial-outwash deposits.

WATER IN GLACIAL-OUTWASH DEPOSITS.

In the eastern part of the basin, in an area extending from Ephrata, Soap Lake, and Adrian, to the vicinity of Moses Lake and beyond, the principal water-bearing formation consists of rudely stratified deposits of waterworn and water-sorted sand, gravel, and boulders. In some places this formation lies on the lake beds, and in others it lies directly on the basalt. Owing to irregularities in the surface on which it rests and in its own upper surface its thickness is variable, ranging from only a few feet to 90 feet or more.

Being unconsolidated and containing a large proportion of coarse material, the glacial-outwash deposits allow very free circulation of water. Wells in this material yield large quantities with very little lowering of water level. In the Moses Lake region large supplies for irrigation are obtained from wells that are sunk only 2 or 3 feet below the water level. One such well was tested in connection with the present investigation—a well on the farm of George C. Hill at

Mae. This well is $3\frac{1}{2}$ feet square and 78 feet deep and is equipped with a 12-horsepower gasoline engine and a 3-inch horizontal centrifugal pump. At the beginning of the test, before the pump was started, the water stood 74.6 feet below the surface of the ground. When the pump was started the water level was rapidly drawn down to 74.9 feet, but was not further lowered during a 20-minute test. The drawdown was, therefore, only 0.3 foot. The discharge as measured was 270 gallons per minute. When the pump was stopped the water level rose immediately to its normal position of 74.6 feet below the surface. Owners of many other wells in this region report equally good results.

The glacial-outwash deposits receive (1) water that falls as rain or snow on that part of Quincy Valley underlain by the outwash deposits and sinks directly into them; (2) water that falls on the extensive drainage basin of Crab Creek and is poured into Quincy Valley either as surface water or as underflow of Crab Creek; (3) water that falls on the elevated region east of Quincy Valley and south of the drainage basin of Crab Creek and is carried in freshets to the valley, where part of it sinks into the outwash deposits; (4) similar storm waters from the eastern part of the Badger Hills and the central part of Quincy Valley; (5) water from the basalt under the plateau north of the basin and from the basalt and overlying lake beds in the western and central parts of the basin, which enters the outwash deposits from the northwest or west; (6) water that falls on the region east of Quincy Valley, percolates into the underlying basalt, and moves westward toward the basin. (See Pl. XIV.) It will be seen, therefore, that the Moses Lake region of Quincy Valley forms a sort of huge trap for the water that falls on it and on a large adjacent region. The only outlets are (1) the gap of lower Crab Creek, (2) the cavities in the basalt of the Frenchman Hills, and (3) the atmosphere, which removes large quantities of water that is at or near the surface. No water is contributed from the Grand Coulee, for Soap Lake, which lies at the mouth of the coulee, never overflows, and it is separated more or less effectively from the outwash deposits of Quincy Valley by a ledge of basalt. The alkaline character of its water shows that it does not discharge by underflow.

The most important sources of water in the outwash deposits are the first two mentioned. The underflow from the west must necessarily be small. The basalt formation beneath the region east of the basin apparently dips very gently toward the basin, but it is deeply trenched by coulees that interrupt the migration of water through it. Some ground water no doubt reaches the Moses Lake region from the east through porous lava beds that are continuous beneath the coulees, but the contributions from this source are probably not large.

The movements and disposal of water from the drainage basin of upper Crab Creek is for convenience shown diagrammatically in

figure 7. This water enters the basin partly as surface flow and partly as underflow.

The surface flow divides a short distance below Adrian, a part going southward through a channel locally known as Willow Creek into Parker Horn of Moses Lake, and the other part going westward a short distance on the north side of the Great Northern Railway into a large, shallow basin known as the Adrian Sink. In the earlier part of a flood most of the water takes the latter course, and it continues to flow in this direction until the sink is filled, after which the water goes down the channel leading into Moses Lake.

Both from Adrian Sink and from the channel leading to Moses Lake water percolates into the glacial gravels and slowly moves underground in a general southward direction. Part of this water reappears in large springs at the head of Rocky Ford Creek, and thence flows into Moses Lake. The rest moves southward through the gravels, a part seeping into Moses Lake and a part eventually reaching the surface in the springs, ponds, and swampy tracts of the sand-dune area south of the lake.

Moses Lake receives water from streams, precipitation on its surface, and underground seepage; and discharges water by surface

flow through its outlet, by evaporation from its surface, and by seepage through its sides and bottom. As shown by the slope of the water table toward the lake (Pl. XIV), ground water enters the lake along almost its entire length on the east side and along the northern part of its west side. Similarly a slope of the water table away from the lake indicates a loss of water along the west side as

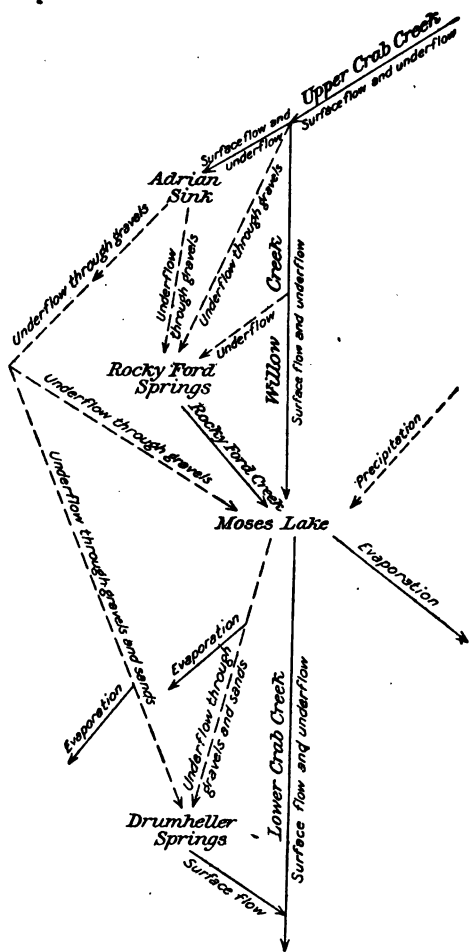


FIGURE 7.—Diagram showing movements and disposal of surface and ground water in the Moses Lake region of Quincy Valley, Wash.

far north as the big bend 4 miles north of Mae. In the sandy country near the south end of the lake the loss by seepage is considerable. Farther north, however, loss by seepage appears to be small in spite of the decided slope of the water table away from the lake, for water levels in wells very close to the lake are considerably below the lake level, a condition that obviously could not exist if there were any considerable seepage from the lake. The sides of the lake along this stretch are formed of gravels that differ little in texture and composition from the water-bearing gravels found in wells throughout the region. Through these gravels the water generally moves with the greatest freedom, and the comparative imperviousness of the gravels forming the lake shore must be ascribed to an extraneous cause, such as natural puddling or a sealing of the pores by silt or vegetal growth, or possibly to some extent by the precipitation of chemical substances. Much of the water that seeps out of the lake returns to the surface farther south.

The amount of water annually available from the outwash deposits is to some extent indicated by the amount that enters the area and by the amount that is discharged. Concerning the part that is added through stream flow and precipitation, approximate information is available, but the amounts entering as underflow are unknown.

The following table, compiled chiefly from measurements and estimates made by F. F. Henshaw, of the United States Geological Survey, based on stream-flow records collected by the Geological Survey and on precipitation records by the Weather Bureau, both in co-operation with the Grant Realty Co., summarizes the available data:

Additions to and losses from water supply of Moses Lake region, Quincy Valley, 1910 to 1913, inclusive.

	1910	1911	1912	1913
	<i>Acre-feet.</i>	<i>Acre-feet.</i>	<i>Acre-feet.</i>	<i>Acre-feet.</i>
Flow of Crab Creek at Adrian ^a	27,800	10,900	3,760	.....
Flow of Crab Creek at Neppel ^a	19,000	5,000	0	84,700
Loss between Adrian and Neppel, chiefly by percolation into the glacial-outwash deposits.....	8,800	5,900	3,760	.....
Flow of Rocky Ford Creek representing ground water that returns to the surface north of Moses Lake.....	50,000	35,100	38,500	42,000
Evaporation from Moses Lake.....	24,200	26,400	27,800	30,200
Precipitation on Moses Lake.....	3,790	3,120	4,000	3,780
Net loss from Moses Lake by excess of evaporation over precipitation.....	20,410	23,280	23,800	26,420
Surface outflow from Moses Lake.....	26,000	0	0	22,700
Increase in lake storage.....	8,510	12,000	10,970	17,740
Discharge from Drumbheller Springs.....	13,430	12,090	^b 12,000	^b 12,000
Discharge from springs above Drumbheller Springs.....	2,800	3,090	1,740	2,300
Evaporation from ponds in the sand-dune area ^c	9,200	9,200	9,200	9,200
Total ground-water discharge south of Moses Lake, exclusive of evaporation and transpiration from swampy areas.....	25,430	24,380	22,940	23,500

^a Stream-flow records incomplete.

^b Estimate based on run-off for previous years.

^c Estimates based on assumption that the open-water surface of the ponds aggregate 2,000 acres and that the average annual evaporation is equivalent to a depth of water of 4.6 feet, the same as for Moses Lake.

In the northern section of the Moses Lake region the ground-water discharge is represented by the flow of Rocky Ford Creek, the evaporation in the swampy tracts north of the lake, and the seepage into the lake. In the southern section it is represented by the flow of Drumbheller and other springs and the evaporation from the ponds and swampy tracts south of the lake. Some of the ground water discharged from the northern section no doubt passes underground a second time and is again returned to the surface in the area south of the lake. (See fig. 7, p. 153.) The total discharge amounts to some tens of thousands of acre-feet a year. Not all this water can be recovered for irrigation, for much is lost by evaporation from the surface of Moses Lake or becomes unavailable by passing into the lake at its north end and discharging at the south end into the sand-dune area, where it can not be used for irrigation. If it were not for the existence of Moses Lake the loss from the underground reservoir would be much less and the available supply would be much greater.

The supply is, however, certainly adequate for much more irrigation than is at present practiced. In view of the large contributory area and the excellent intake facilities afforded by the deposits of sand and gravel it is not probable that the demands for irrigation in the Moses Lake region will exceed the supply. It is believed that the above data show that an additional 5,000 acres can be irrigated in this region.

QUALITY OF WATER.

Analyses of samples of 13 ground waters and 6 surface waters, which were made in order to determine the quality of water in this basin, will be published in a later report. In general, these analyses indicate a very favorable condition of the ground waters. The waters represented by 11 of the samples are classed as good and 2 as fair for irrigation. Most of them are calcium-carbonate in character, only 1 containing in predominating amounts sodium and carbonate, the constituents of black alkali. Even this water, however, is good for irrigation and would not damage even the most sensitive crops, unless used in a grossly careless manner. Most of the waters are good or fair for domestic use, but two have been classed as bad, one because of its high mineral content, especially of calcium and magnesium, which cause hardness and excessive consumption of soap in washing, and the other because of its high content of bicarbonate.

The surface waters analyzed vary more widely in their value for irrigation and domestic use. Two samples from different points in Moses Lake show this water to be sodium-carbonate in character but sufficiently low in these and other mineral constituents to be entirely satisfactory for irrigation and for domestic use.

The water from a pothole in the NW. $\frac{1}{4}$ sec. 22, T. 19 N., R. 25 E., was found to be fair only for domestic use and for irrigation. Soap

Lake, Grimes Lake, and a lake in Grand Coulee, 5 miles above Coulee City, all furnish water which is too highly mineralized to be useful as domestic supplies. The waters from Soap and Grimes lakes are classed as bad for irrigation and could not be economically used for this purpose. The water from the lake in Grand Coulee might be used in irrigating some of the crops less sensitive to alkali if liberal quantities of land plaster were applied to the land, but even then such special precautions as artificial drainage or washing down the alkali by flooding¹ would probably be necessary to insure success.

PUMPING PLANTS AND IRRIGATION.

PUMPING FROM WELLS.

Most of the water used for irrigation in Quincy Valley is pumped from wells, but a part is pumped from Moses Lake.

Power for pumping is supplied by internal-combustion engines burning distillate or crude oil. The power plants range in size from 5 to 80 horsepower, but 15 to 30 horsepower is the size of most plants designed primarily for irrigation. The pumps are either centrifugal or reciprocating, the type selected depending on the lift. The lifts range from 10 to 300 feet, and the yields from 25 to 1,000 gallons per minute. Centrifugal pumps (ordinary centrifugal or turbine) are generally used for lifts of less than 100 feet; for the greater lifts reciprocating (plunger or piston) pumps are used.

In 1916 wells were used to irrigate approximately 2,800 acres in the basin, exclusive of lands in the vicinity of Ephrata and of Soap Lake—2,300 acres being in orchard, mostly apples, and 500 acres in alfalfa and miscellaneous crops. In the Ephrata and Soap Lake regions perhaps 500 acres additional were irrigated from wells, making a total of 3,300 acres for the whole basin. Several factors, among which may be mentioned character of soil, accessibility of water supply, and nearness to transportation lines, have restricted irrigation to certain fairly well defined districts. Thus the Quincy and Winchester districts were selected for development chiefly because of the good quality of the soil and nearness to the railroad; Hiawatha Valley and the Moses Lake region because water could be obtained near the surface. All attempts to irrigate large tracts in the south-central and southern parts of the basin by pumping have resulted in failure because the soil is so porous and absorbs the water so rapidly that the land can not be covered by the ordinary irrigating stream.

¹ See Dole, R. B., Ground water in San Joaquin Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 398, pp. 58-61, 1916.

PUMPING FROM MOSES LAKE.

In 1916 approximately 700 acres were irrigated by pumping from Moses Lake. The Grant Realty Co. has six pumping plants that draw from the lake, four of which were in operation in 1916. The plants range in size from 11 to 90 horsepower and are designed for capacities of 1,400 to 2,600 gallons per minute with heads of 45 to 95 feet.

COST OF PUMPING.

In calculating the cost of pumping, not only the actual expenses of operation should be considered but also all fixed charges, such as interest on the investment, depreciation, taxes, and repairs. Annual charges for depreciation and repairs on the average plant will range from 12 to 15 per cent of the cost of the equipment and interest and taxes from 7 to 9 per cent.

The cost of fuel is probably the largest item of the operating expense. With distillate costing 14 cents a gallon, the expense for fuel at 30 plants in Quincy Valley in 1916, as reported by the owners, ranged from \$1.50 to \$18 per acre-foot of water pumped. The average cost was about \$2 for an acre-foot of water lifted 50 feet. At a few plants a lower grade of distillate, known as "stove oil" or "stove distillate," costing about 6 cents a gallon, was used and the cost of pumping at these plants was materially less. The principal reason given for using the more expensive fuel is that the use of the cheaper fuel necessitates a special carbureter for the engine, but as the carbureter can be purchased at a comparatively small expense it seems poor economy to avoid an immediate outlay by continuously meeting a fuel bill that is higher than necessary.

SUMMARY AND CONCLUSIONS.

Water for irrigation can be obtained in Quincy Valley only by pumping. In 1916 lands aggregating about 3,300 acres were irrigated by pumping from wells and about 700 acres by pumping from Moses Lake.

Power for pumping is supplied entirely by internal-combustion engines. Because of the high cost of fuel the cost of water for irrigation is high, especially throughout the central and western parts of the basin, where water must be lifted from great depths.

On the basis of the acreage now under irrigation and the probable annual contributions of water to the basalt, lake beds, and glacial-outwash deposits and to Moses Lake, it is estimated that a total of as much as 15,000 acres can be irrigated in the basin each year from these sources, the most dependable of which are the glacial-outwash deposits and Moses Lake. Irrigation projects planned to serve more than 15,000 acres are not justified by the facts at present available.

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